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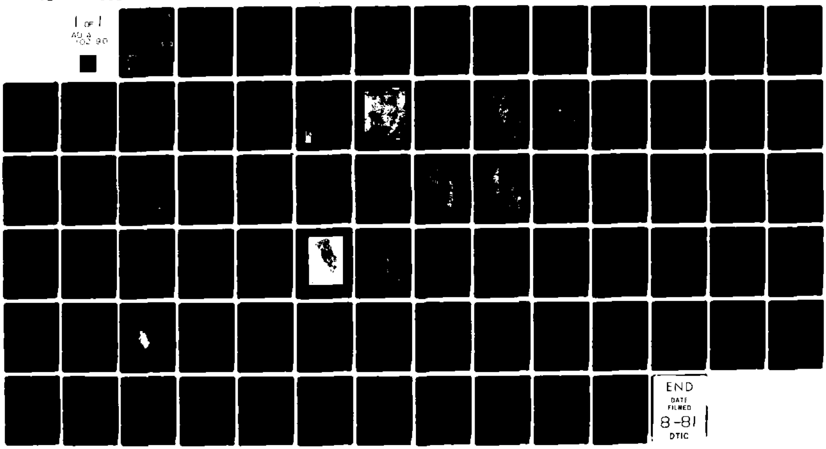

RESEARCH NOTE NO. 7

DETERMINATION OF LAND USE FROM LANDSAT IMAGERY: APPLICATIONS TO HYDROLOGIC MODELING

NOVEMBER 1979

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An operational procedure for determining land use from LANDSAT imagery was applied to five watersheds: Crow Creek, Walnut Creek, Rowlett Creek, Pennypack Creek, and Castro Valley (University of California, Davis (USD) staff performing the work on the latter three watersheds). Based on this work the following conclusions can be made: (1) At the grid cell level LANDSAT land use was in error approximately one-third of the time. (2) By aggregating land use over the entire watershed, LANDSAT's average misclassification of land use reduces to 2-8% for the (CONTINUED)

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major land use categories. (3) The commercial classification was less accurate at the grid cell level than the UCD procedure classification; errors at the watershed level were nearly the same for both. (4) Evaluated in terms of the difference in discharge frequency curves derived using the same hydrologic model but different land use (LANDSAT and conventional), the LANDSAT derived land use found to be completely adequate. The number and type of land use categories derived from LANDSAT data were sufficient to be able to apply two standard hydrologic modeling techniques; Snyder's unit hydrograph and percent imperviousness and the SCS curve number method. (5) the UCD procedure works. It is a complete, self-contained package of computer programs and manual operations that permit a user to identify land use from LANDSAT digital data without requiring the use of expensive interactive image processing equipment. (6) LANDSAT land use can be directly incorporated into a grid cell data bank, thus providing and automated environment for applying the LANDSAT classification in routing hydrologic investigations.

DETERMINATION OF LAND USE FROM LANDSAT IMAGERY:
APPLICATIONS TO HYDROLOGIC MODELING

HEC/UCD/NASA Water Management and Control ASVT
Final Report

The Hydrologic Engineering Center
U. S. Army Corps of Engineers
Davis, California

November 1979

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DETERMINATION OF LAND USE FROM LANDSAT IMAGERY: APPLICATIONS TO HYDROLOGIC MODELING

The Hydrologic Engineering Center
U.S. Army Corps of Engineers
Davis, California

INTRODUCTION

The purpose of this report is to document work completed over the past year at the Hydrologic Engineering Center (HEC) in the area of "remote sensing and land use." This work has been performed in a cooperative effort with the University of California, Davis (UCD) and the National Aeronautics and Space Administration (NASA) as part of a NASA Water Management and control ASVT (Application Systems Verification and Transfer). The project participants are listed in Appendix A.

One of HEC's mission objectives is to take new and promising technology that is applicable to hydrologic engineering and water resources planning, test it in a "real world" application, and (if results are satisfactory) make it conveniently available to Corps of Engineers' field offices. The use of remote sensing, in particular the LANDSAT series of satellites, to determine land use for input to hydrologic models is an example of the technology transfer from the research community to the working environment of the Corps of Engineers.

The various components of the NASA ASVT project have been consistent with this philosophy of providing a useable product. UCD developed an operational procedure for land use classification using LANDSAT digital data and tested it on four watersheds. HEC has tested the procedure on two additional watersheds, has compared LANDSAT and conventional land use in four basins, and has determined the hydrologic significance of the difference between LANDSAT and conventional land use classifications for three of these basins (Cermak, 1979). HEC has also contracted with a commercial organization to classify one of the same watersheds that has previously been analyzed using the UCD procedure, thus permitting an additional comparison of output product quality and cost. NASA has engaged a consultant to conduct a formal cost-effectiveness study of LANDSAT land use classification, to which HEC has provided cost and labor information.

This report will begin with an explanation of the relationship between hydrologic modeling, land use, and LANDSAT. Next, the use of grid cell data banks and HEC's spatial data management system for comparing alternative land use classifications are described. A general discussion of LANDSAT and conventional land use comparisons will precede a detailed land use analysis of five study basins. HEC's experience with the commercial classification of some of these same basins will be reported, followed by a tabulation of relevant cost data. Finally, hydrologic simulations of three watersheds, based on both LANDSAT and conventional land use, will be described. From this analysis, an evaluation will be given of the use of LANDSAT land use in the hydrologic modeling process.

HYDROLOGY, LAND USE, AND LANDSAT

The hydrologic modeling of a watershed, particularly urban or urbanizing basins, requires that the distribution of land use be determined. The amount and timing of runoff is directly related to the infiltration capacity of a land area with the most important distinction being between pervious and impervious land surfaces. Water quality parameters have a similar dependence on land use data; rate of accumulation of a particular pollutant per unit area is normally expressed as a function of land use. Water resource planning studies are interested in not only an assessment of the present state of the water and related resource system, but also its possible future configuration. By expressing hydrologic parameters as a function of current land use it becomes possible to rationally predict the impact future land use changes will have on the quantity and quality of future runoff.

Manual methods for land use identification (e.g., interpretation of low altitude aerial photography and field surveys) are frequently used in watershed studies. With this approach, the resource requirements, both money and labor, for manual classification can be extensive. An attractive alternative is the utilization of available remote sensing systems and computer-assisted classification techniques.

The LANDSAT satellites have been shown to have the capability of providing land use data at acceptable levels of accuracy for hydrologic modeling purposes (Algazi, 1977b; Burgy, 1974; Jackson, 1977; Ragan, 1975). LANDSAT data is quicker and less costly to obtain and interpret than low altitude aerial photography, provides repetitive coverage of the same area at least every 18 days, and is available for all United States and many worldwide locations. Additionally, LANDSAT's digital format can be directly analyzed by several available classification computer programs, and can be resampled for automatic inclusion in a geographic data bank.

Different physical features on the earth's surface reflect different amounts of light in certain wavelength intervals. This is the basic principal upon which LANDSAT[1] operates. By identifying a spectral pattern or "signature" that is consistently associated with a particular land use, it is possible to classify major land cover categories over large areas directly from the LANDSAT data. "For example, vegetation typically reflects more green light than red and is more reflective (bright) in the infrared. Many dry soils, by contrast, reflect less light in the green than in the red and moderately more so in the infrared; wet soils show similar patterns of relative reflectance in the four bands but the magnitude or intensity of light reflected in each band is reduced by the general light-absorbing character of water" (Short, 1976).

[1]See Appendix B for background information on LANDSAT's orbital characteristics, sensor system, and data formats.

GRID CELL SPATIAL DATA MANAGEMENT SYSTEM

The Corps of Engineers' Expanded Flood Plain Information Studies (XFPI) provided a mechanism for evaluating LANDSAT land use classifications. The XFPI pilot studies undertaken by several Corps district offices analyzed the hydrologic, economic, and environmental aspects of existing and alternative future land use patterns. The analyses included the automatic computation of expected annual flood damages which resulted from changed hydrologic responses and/or stage-damage functions as related to each land use pattern and flood management measure. Example XFPI studies are described in U.S. Army Corps of Engineers (1975; 1978c).

A comprehensive spatial data management system developed at the HEC (Davis, 1978) was used in the XFPI studies for the following purposes: (1) to encode, check and place geographic map data in a grid cell data bank; (2) to display the data through plotting maps of one or more variables by their absolute values or by weighted combinations of relative attractiveness; and (3) to extract data from the data bank and to formulate parameters for hydrologic, economic and environmental simulation programs. The principal computer programs for data bank input, hydrologic parameter identification and watershed simulation, and their relation to the UCD LANDSAT land use classification programs are shown in Figure 1.

Each XFPI grid cell data bank contained an existing land use variable which was classified by conventional means. This allowed an exhaustive cell-by-cell comparison between the conventionally classified land use and the corresponding LANDSAT land use classification using the computer program RIA (U.S. Army Corps of Engineers, 1978b). Hydrologic parameters, expressed as a function of several spatial variables including land use, were calculated for both the conventional and the LANDSAT land use classifications by using the computer program HYDPAR (U.S. Army Corps of Engineers, 1978d). Using the HEC-1 watershed model (U.S. Army Corps of Engineers, 1973), which had been calibrated to each of the individual basins by the responsible Corps district office, the significance of the hydrologic differences between the two land use classifications was assessed.

UCD PROCEDURE

An operational procedure for land use classification from LANDSAT data has been developed at the University of California, Davis (UCD) for use by the Corps of Engineers. Referred to as the UCD Procedure, it was designed to function under the following constraints:

(1) Use of dedicated, interactive image processing facilities would <u>not</u> be required. Only output equipment normally available in Corps' field offices (e.g., line printer) and batch-mode access to a general purpose computer could be expected.

(2) Would <u>not</u> require additional software beyond that provided as part of the procedural package.

(3) Would <u>not</u> require specialized technical expertise in data analysis, computer programming, or remote sensing.

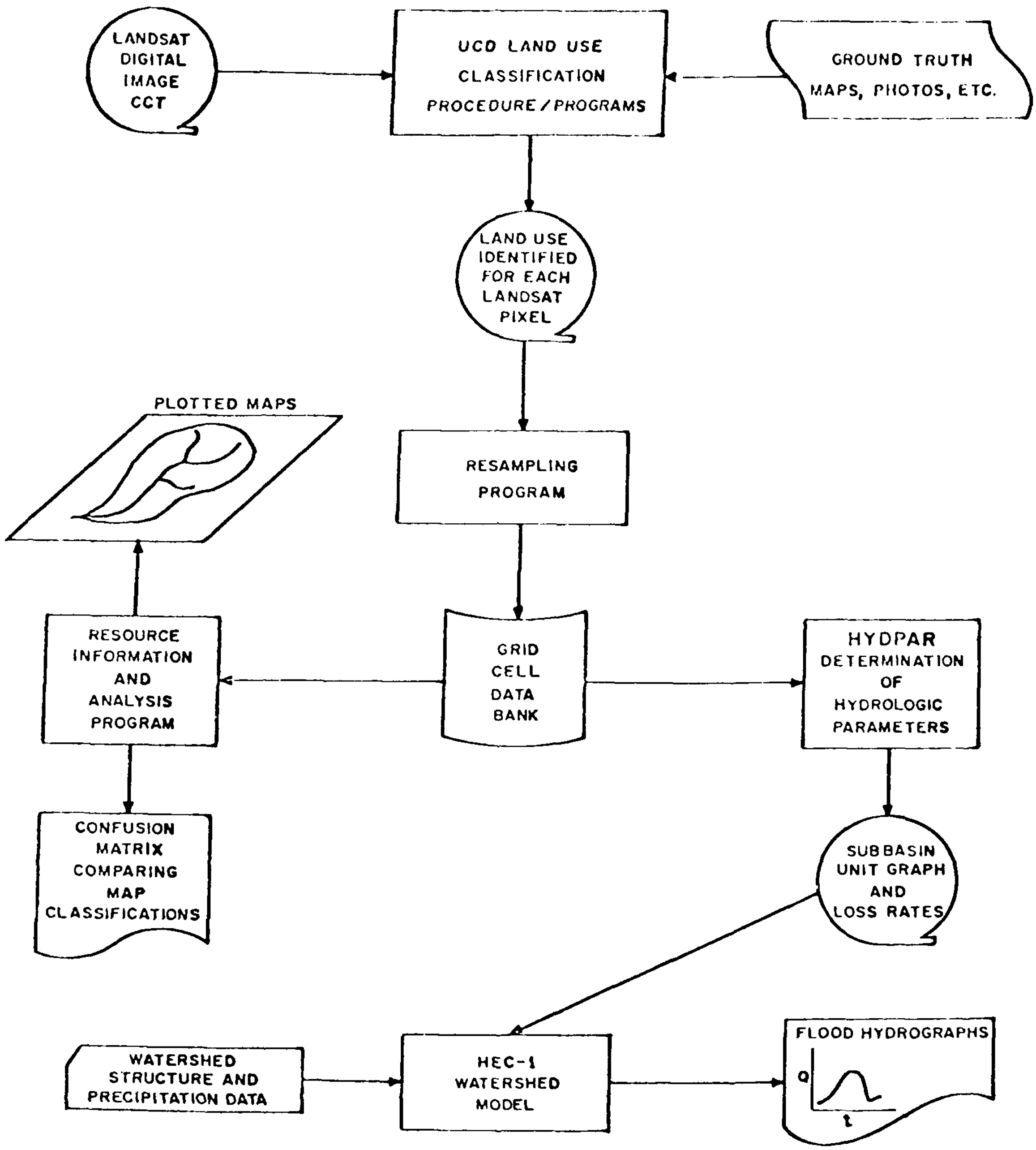


Figure 1 SCHEMATIC OF PROCESSING SYSTEM

(4) Would provide a usable product; i.e., one that can conveniently be entered into a grid cell data bank and that will adequately, from a hydrologic viewpoint, represent current land use conditions.

The UCD procedure consists of an organized set of computer programs and manual operations for the identification of land use from raw LANDSAT data. A detailed description of the procedure is given by Algazi (1979) and Meyer (1978). What follows is a brief outline of the primary tasks:

(1) Obtain LANDSAT Computer-Compatible Tapes (CCT), NASA high altitude aerial photography, and USGS topographic maps for the location and date of interest. Extract a rectangular area of data containing the watershed from the CCT. Check for radiometric errors in the LANDSAT digital data and, if necessary, correct.

(2) Determine the geometric registration of the LANDSAT image with the coordinate system of the topographic maps. LANDSAT control points are identified from the output of a UCD computer program which enhances roads and water bodies found in the LANDSAT image. A regression equation, estimated from the two sets of control points, provides a transformation mechanism for going between the image coordinate system and the map coordinate system, Universal Transverse Mercator (UTM).

(3) Use an unsupervised clustering algorithm[1] to partition the LANDSAT four-dimensional data space. Groups or "clusters" are identified that contain points with spectral reflectance values that are similar to members of the same cluster, and dissimilar to the points of other clusters. The clustering program is allowed to generate a maximum of 30 clusters. Each pixel in the watershed data is assigned to a cluster.

(4) Select from a line printer map of the cluster assignments six sets of adjacent pixels (spatial groups), all belonging to the same cluster. Their corresponding location on the topographic maps is determined using the transformation equation of step (2). Visual translation, from the map to the aerial photographs, of the spatial group's location permits a land use to be assigned to each spatial group. For clusters having a consistent land use assigned to all six spatial groups, a final land use has been determined. But for those clusters where conflicts exist between the land use identified with each of the six spatial groups, further partitioning of the data space is required.

(5) Clusters with conflicting land use assignments and clusters whose associated land use could not be determined from the available maps and photos are reclustered by repeating step (3), and given final land use assignments by repeating step (4).

(6) At this point the watershed data file contains a land use classification (typically 5 to 7 categories) for all its pixels. The watershed file is then resampled at the grid cell centroids using a

[1]See Appendix C for a desciption of ISOCLAS, the UCD Procedure's clustering algorithm.

nearest-neighbor algorithm. The size of the grid cells is usually line printer compatible with the scale of USGS 7-1/2-min. topographic maps.

(7) The resampled file is entered directly into a grid cell data bank. Alternatively, a file containing the digitized (in UTM coordinates) watershed boundary can be used to mask the resampled file, leaving only the grid cells within the boundary. Total acreage of each land use class for the entire watershed is then computed.

LANDSAT - CONVENTIONAL LAND USE COMPARISON

The UCD Procedure has been applied by the UCD staff to four watersheds (Trail Creek, Castro Valley, Pennypack Creek, and Rowlett Creek) and by the HEC staff to two watersheds (Crow Creek and Walnut Creek). Detailed comparisons of LANDSAT and conventional land use classifications for these basins will be presented.[1] First, however, it is necessary to discuss what factors influence land use classification accuracy, what is being compared, and what qualifications should be kept in mind before interpretations and conclusions are made from the comparison results.

LANDSAT Land Use

The quality of a LANDSAT land use classification is a function of several factors; some are within human control but others reflect inherent limitations of the sensor system. It has been found that scale and date of ground truth data are critical variables. If the scale of high altitude aerial photography is too small to identify land features or if the date of the photography is quite different from the date of the LANDSAT imagery, then it becomes very difficult to make accurate land use assignments to the cluster spatial groups. Personal knowledge of a study basin and experience and skill of the analyst are also important when it comes to interpretation of aerial photography.

LANDSAT itself is limited by its maximum resolution to areas no smaller than a pixel (about 1.11 acres). Spectral reflectance is averaged over the entire pixel, providing the opportunity for two very different physical features (e.g., rooftops and lawns) to appear spectrally the same to LANDSAT as some third category (e.g., agricultural land). Another problem is that land use classes that we would like to discriminate between may have very similar spectral signatures (e.g., high density residential and small commercial buildings). Potentially, the algorithm used to identify spectral patterns in the LANDSAT data may influence the quality of the final classification. Based on our experience with different classifiers, however, there appears to be no major difference in the accuracy level of the available classification procedures.

[1] LANDSAT land use for Trail Creek has been reported elsewhere (Algazi, 1977a) and will not be repeated here. Because only LANDSAT land use has been determined for Crow Creek, no comparison with conventional land use was possible.

Conventional Land Use

The existance of grid cell data banks was the criteria for selecting which watersheds would be subjected to a land use comparison. Each data bank (previously created by either a Corps District or HEC) contained an "existing" land use variable that had been determined by conventional means, usually manual interpretation of low-altitude aerial photography. It was to this classification, referred to as conventional land use, that the LANDSAT land use was compared. Obviously the meaningfulness of the comparison would depend on the degree to which conventional land use actually represented "real world" conditions on the date the LANDSAT imagery was taken. Among the watersheds examined, variation in quality of the conventional land use was noticed. For some basins, low-altitude photographic coverage was flown and the resulting photo mosaic interpreted specifically for encoding into a grid cell data bank. But for others, "existing" land use was determined by encoding land use boundaries from local agency land use planning maps and USGS topographic maps. Land use planning maps will often show what "should be" or "will be", rather than what "is". Conventional land use based on such data may be of questionable accuracy.

Land Use Comparison

When comparing LANDSAT and conventional land use, it is important to recognize that the same land cover can be interpreted differently; i.e., conventional land use categories are not always compatible with LANDSAT land cover categories. For example, the conventional category "transportation/communication/utilites" includes major highways, right-of-way for railroads and power transmission lines, communication towers, airport facilities (including buildings, runways, and vacant land within the airport limits), and sewage treatment plants. In contrast, LANDSAT will recognize the treatment plant settling tanks as "water bodies", the open fields surrounding a runway as one of the vegetation categories, and right-of-ways as whatever land cover class is nearby.

A comparison at the grid cell level can be thought of as a comparison at the pixel level; both units of area are nearly the same size.[1] At this scale errors introduced during the geometric correction and resampling steps of the UCD Procedure will be erroneously interpreted as LANDSAT misclassification errors. This will be particularly true of land use categories defined by a small number of adjacent pixels. The border areas of the larger land use categories are also susceptible to geometric problems.

For hydrologic modeling purposes, accuracy at the grid cell level is not necessary. Typically the smallest unit of analysis in hydrologic modeling is the subbasin; Pennypack Creek, for example, was modeled (U.S. Army Corps of Engineer, 1978a) using subbasins ranging in size from 0.17 sq. mi. (109 ac) to 4.03 sq. mi. (2579 ac). In determining model parameters, land use for the

[1]The pixel is approximately 1.11 acres; grid cells for Castro Valley, Walnut Creek, Rowlett Creek and Pennypack Creek are 1.53 ac, 1.15 ac, 1.15 ac and 0.74 ac, respectively.

individual grid cells is aggregated for all cells within a subbasin boundary. Further aggregation of subbasin land use gives the distribution of land use over the entire basin. It is at the grid cell level and watershed level that comparisons will be made. The reader should remember that subbasin accuracy, the level of most relevance to hydrology, lies somewhere between these two extremes.

With these qualifications stated, we begin the land use comparison analysis.

Crow Creek

HEC staff learned the mechanics of the UCD Procedure by applying it for the land use classification of Crow Creek. A grid cell data bank for Crow Creek had not yet been constructed by the Rock Island District when this report was completed. Therefore, only the LANDSAT land use classification can be discussed.

Crow Creek, a predominately rural watershed located near Davenport, Iowa, has a drainage area of 18.4 square miles. Dates and specifications of LANDSAT imagery and ground truth data are listed below.

LANDSAT Imagery:

- 18 May 1976, ID # 2482-15585.

Ground Truth:

- NASA high-altitude color infrared aerial photography, 30 Mar 1973, scale = 1:125,000.
- USGS 7-1/2-minute topographic maps, photorevised 1970 and 1975, scale = 1:24,000.
- Mylar copy of Rock Island District's XFPI base map, scale = 1:12,000, (enlargement of topographic maps above with watershed boundary outlined).
- Low-altitude photo-mosaic on screended Mylar, July 1977, scale = 1:12,000.

Seven land use classes were identified from the LANDSAT data: agricultural, residential, industrial/commercial, developed open space, forest, undeveloped open space, and water. Acreage and percent distribution in the various categories are given in Table 1, and illustrated by a line printer map and corresponding topographic map in Figure 2.

Walnut Creek

Walnut Creek was intended to provide a test case for determining the accuracy of LANDSAT land use. It was also a watershed that was to be analyzed both using the UCD Procedure and the services of a commercial vendor. Although conventional land use had been determined for the basin by

the Fort Worth District, a calibrated hydrologic model had not been completed at the time of this study. Therefore, only land use and not hydrologic comparisons could be made.

Table 1

Crow Creek LANDSAT Land Use
Area Table

Land Use Category	Acres	%
Agricultural	7,333	62.2
Residential	1,780	15.1
Industrial/Commercial	78	0.7
Developed Open Space	480	4.1
Forest	859	7.3
Undeveloped Open Space	1,229	10.4
Water	35	0.3
	11,794	100.1

Walnut Creek is located near Austin, Texas and has a drainage area of 55 square miles. Specifications for LANDSAT imagery, ground truth data and conventional land use used in the analysis are listed below.

LANDSAT imagery:
- 3 May 1976, ID #2467-16194.

Ground Truth:

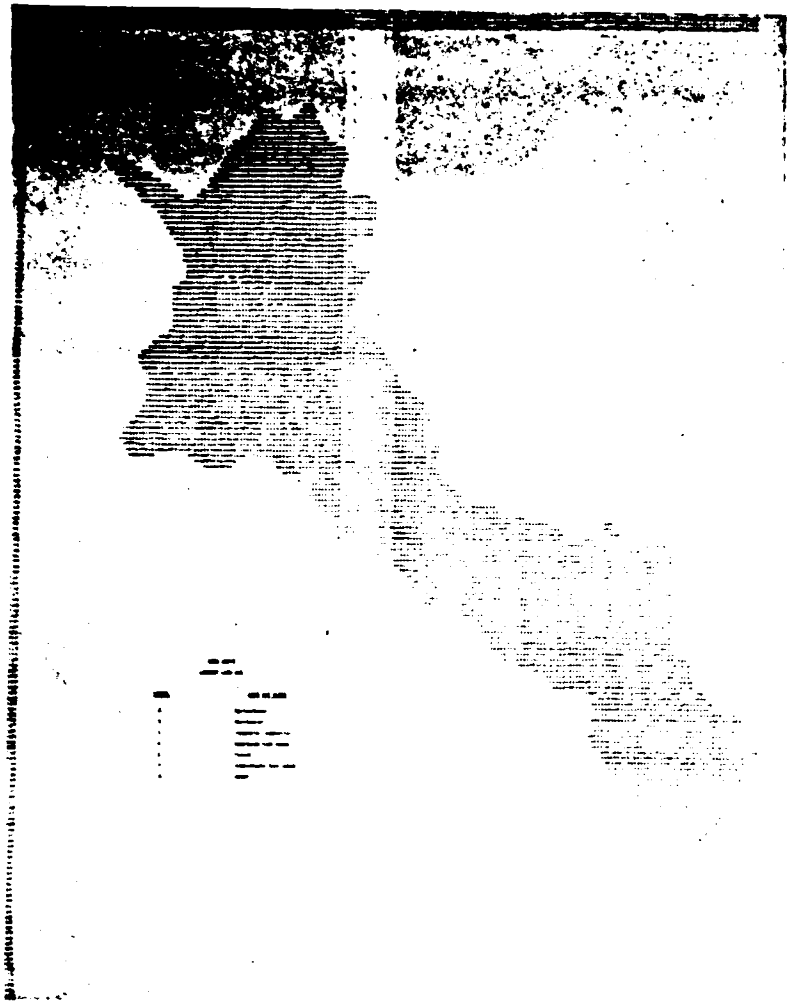
- NASA high-altitude color infrared aerial photography, 21 Jan 1974, scale = 1:121,000.

- USGS 7-1/2-minute topographic maps, photorevised 1973, scale = 1:24,000.

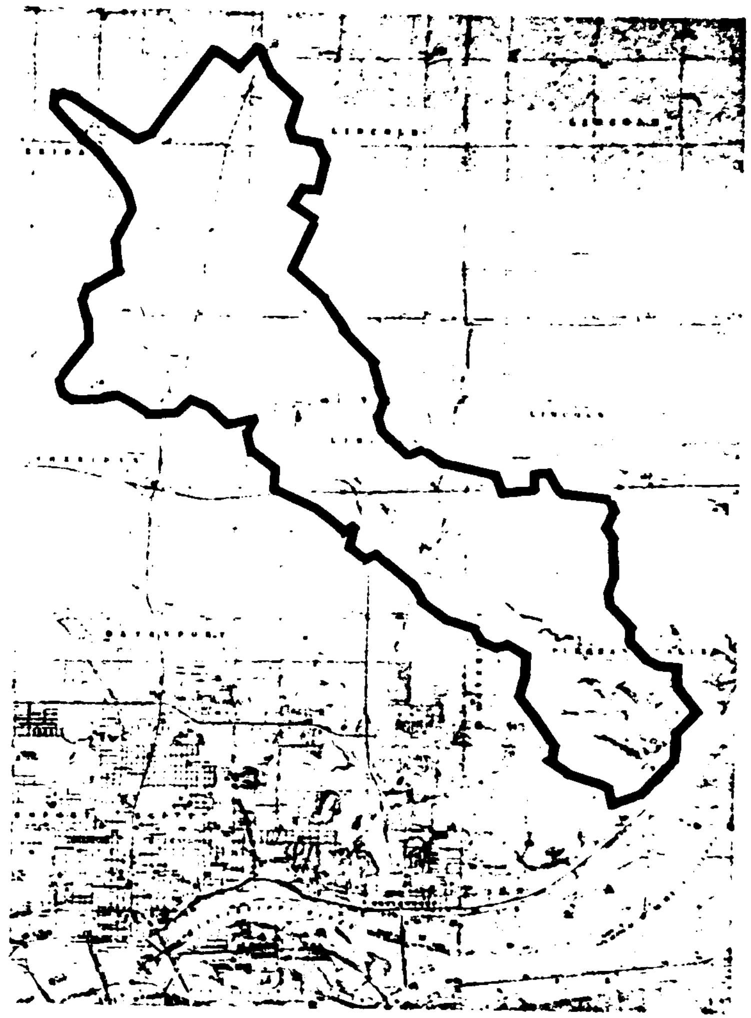
Conventional Land Use:

- Interpreted from low-altitude color infrared aerial photography, Oct 1977, scale = 1:12,000.

The location of Walnut Creek on the LANDSAT scene is shown in Figure 3. The Walnut Creek conventional land use consisted of 19 land use categories, listed in Table 2 along with their respective acreage and percent distribution. Figure 4 is a line printer map of the same classification.



LANDSAT Land Use



Topographic Map

Figure 2
Crow Creek

Figure 3

LANDSAT Scene with Walnut Creek
Watershed Boundary Outlined

Table 2

Walnut Creek Conventional Land Use
Area Table

Land Use Category	Acres	%
Low density residential	1,785	4.9
Medium density residential	3,671	10.0
High density residential	156	0.4
Multifamily residential	619	1.7
Mobile home parks	126	0.3
Strip commercial	264	0.7
Shopping centers	85	0.2
Institutional	536	1.5
Industrial	488	1.3
Industrial/commercial complexes	742	2.0
Public use	96	0.3
Transportation/communication/utilities	1,261	3.4
Barren land/quarry	1,022	2.8
Cropland	3,917	10.7
Pasture/rangeland	11,327	31.0
Developed open space	139	0.4
Undeveloped urban land	1,135	3.1
Forest	9,143	25.0
Water	62	0.2
	36,574	99.9

Using the UCD Procedure six classes of land use were identified from the LANDSAT imagery: cropland/pasture, residential, commercial/industrial, quarry, forest/rangeland, and water. Acreage and percent distribution for the LANDSAT classification are given in Table 3, as is a line printer map in Figure 5.

Table 3

Walnut Creek UCD LANDSAT Land Use
Area Table

Land Use Category	Acres	%
Cropland/Pasture	15,298	41.8
Residential	9,135	25.0
Commerical/Industrial	1,861	5.1
Quarry	223	0.6
Forest/Rangeland	9,988	27.3
Water	70	0.2
	36,575	100.0

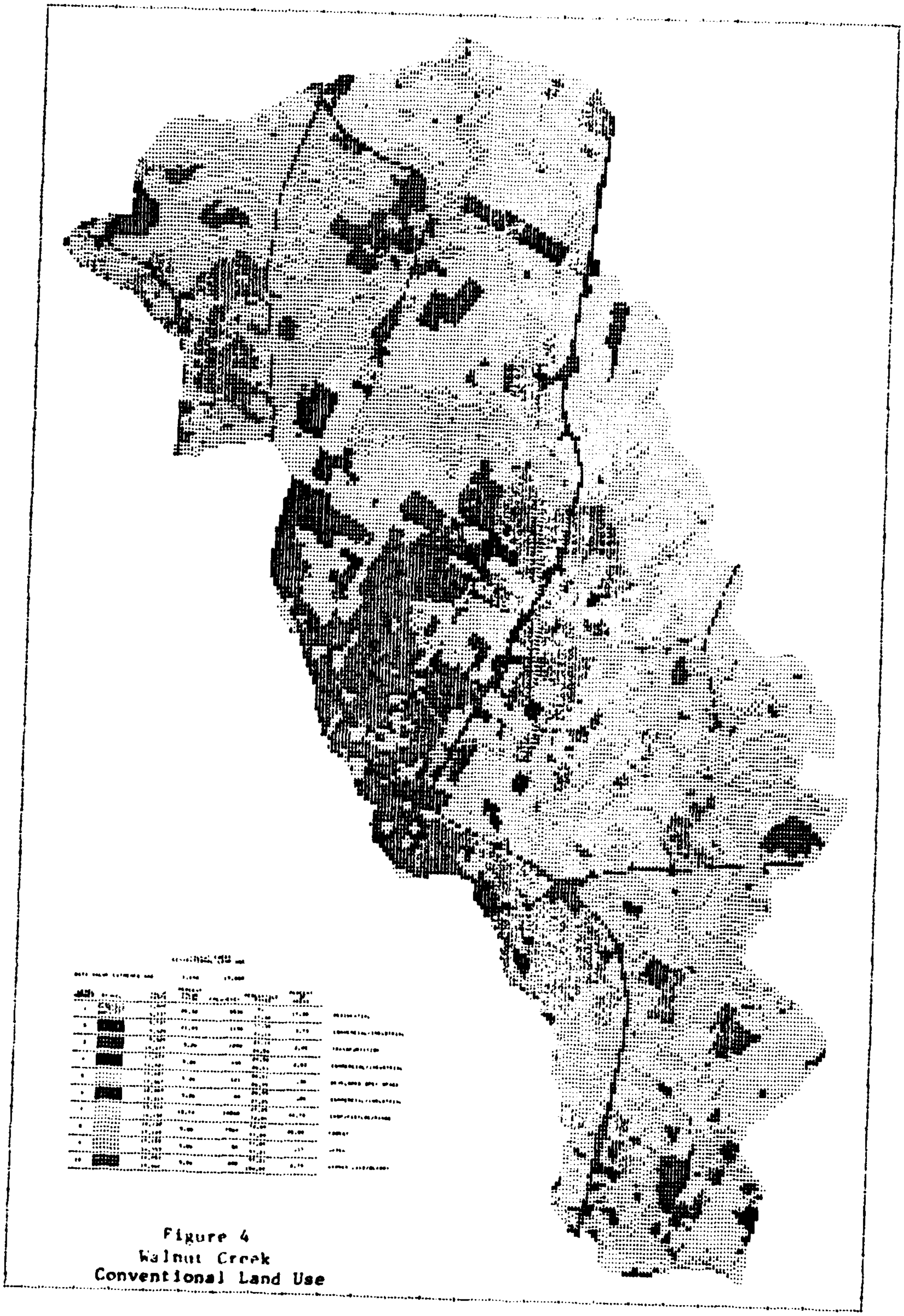


Figure 4
Walnut Creek
Conventional Land Use

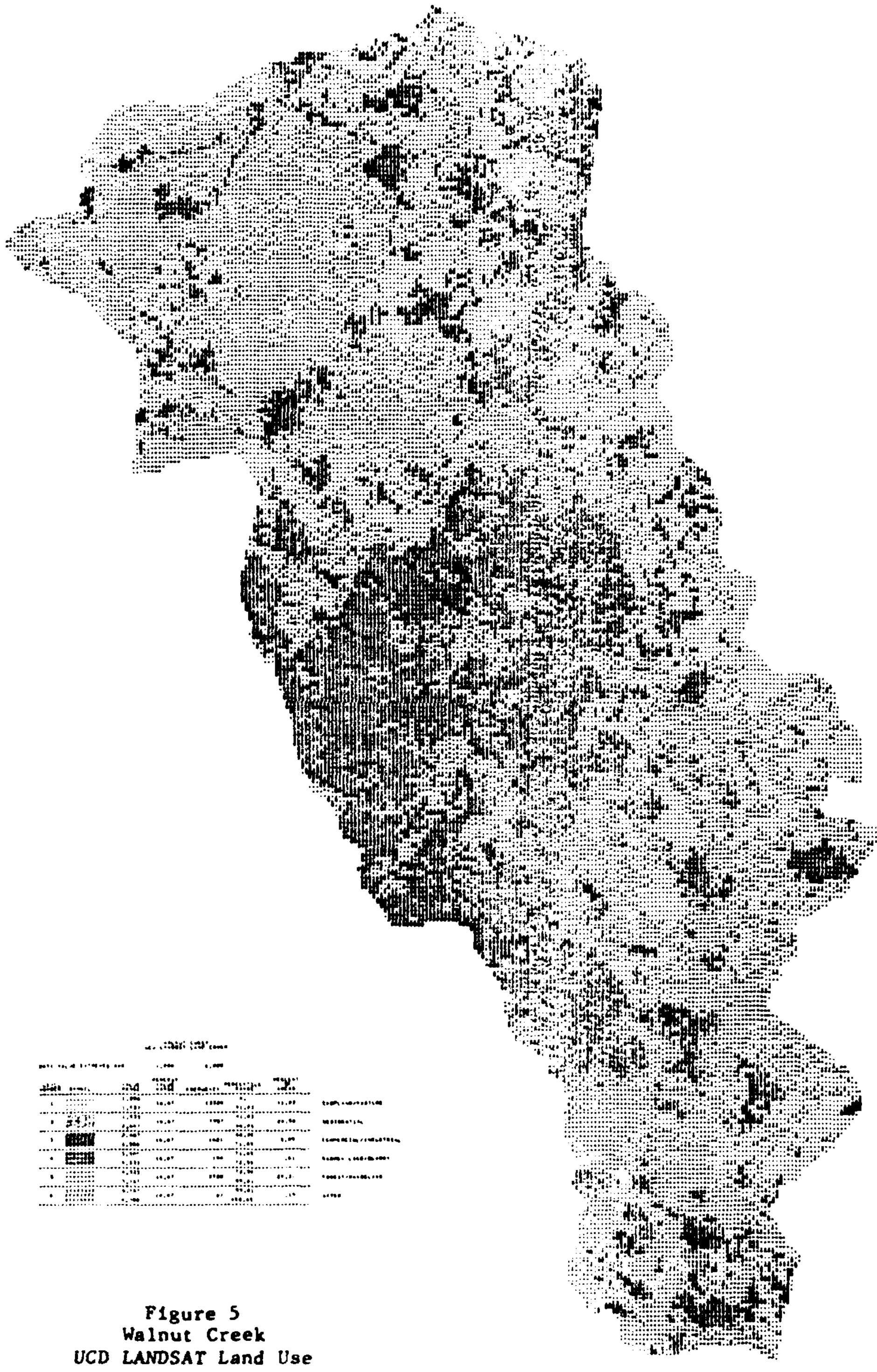


Figure 5
Walnut Creek
UCD LANDSAT Land Use

The LANDSAT land use classification was entered into a grid cell data bank that had previously been constructed by the Fort Worth District for an Expanded Flood Plain Information Study (XFPI) of the Walnut Creek Basin. The grid cell size of the Walnut Creek data bank is 200 feet (east-west) by 250 feet (north-south), or 1.148 acres. Conventional land use was also a data bank variable. The simultaneous existance in the data bank of land use classified by LANDSAT and conventional means permitted an exhaustive comparison of the two approaches.

For a cell-by-cell comparision of the entire watershed it was necessary to establish an explicit mapping of conventional land use categories into the fewer LANDSAT land use categories, Table 4. The RIA computer program (U.S. Army Corps of Engineers, 1978b) generated the coincident matrix, Table 5. The structure of this crosstabulation table is similar to others that will be presented later in this report. Each element of the table (row and column combination) refers to all grid cells within the watershed data bank that have the concurrent LANDSAT and conventional land use specified by the row and column headings of that particular element. For example, the 2nd row, 1st column of Table 5 refers to all grid cells in the Walnut Creek data bank that are classified both commercial/industrial by LANDSAT and residential by the conventional classification. For each element of the table, four numbers are given: (1) total acreage of all grid cells represented by the appropriate joint land use classification; (2) row percent, or the percent of all grid cells with the given LANDSAT classification that have also the given conventional classification; (3) column percent, or the percent of all grid cells with the given conventional land use that have also the given LANDSAT land use; and (4) total percent, or the percent of the entire watershed that has the given joint land use classification. Continuing our example above, 471 acres were found to be classified both commercial/ industrial by LANDSAT and residential by conventional means. This acreage represents 25.3% of all the area (1861 ac) that was classified by LANDSAT as commercial/industrial, 7.4% of all the area (6359 ac) that belonged to the conventional residental category, and 1.3% of the total watershed area (36,578 ac).

The far right column (row total) and the bottom row (column total) of Table 5 give the marginal distributions of LANDSAT and conventional land use, respectively. These represent the acres and percent in the different land use categories without the conditional requirement described above for the body of the table. The marginal distributions are exactly the same information as previously given in the area tables (e.g., Tables 2 and 3), only now aggregated according to the land use category mapping (Table 4).

In interpreting Table 5, the proportion of the entire watershed represented by the grid cells that appear down the upper-left to lower-right diagonal of the table, 52.7%, can be thought of as a measurement of the accuracy of the LANDSAT classification. A strong qualification on the preceding statement is that land use classes are not completely consistent between classifications; as a result, even if LANDSAT was 100% "correct", some grid cells would appear in off-diagonal table elements. A second complication in interpreting Table 5 is the inclusion of rangeland in the "cropland/pasture" conventional land use category, and in the "forest" LANDSAT land use category. Being

unable to differentiate between them, cropland, pasture, forest, and rangeland should be grouped as one category. Summing the diagonal percentages would then result in 70.8% of the grid cells "correctly" classified by LANDSAT.

Table 4

Walnut Creek
Land Use Category Mapping

Conventional Land Use	UCD LANDSAT	Battelle LANDSAT
Low density single family residential Medium density single family residential High density single family residential Multifamily residential Mobile home parks	residential	residential
Strip commercial Shopping centers Institutional Industrial Industrial and commerical complexes Public Use: cemetaries, public assembly areas, waste disposal areas Transportation, communication, utilities	commercial/ industrial	industrial/ commercial transportation
Barren land/quarry	barren land/ quarry	barren land quarry
Cropland Pasture/rangeland Developed open space Undeveloped urban land	cropland/ pasture	cropland/ pasture rangeland
Forest	forest/ rangeland	forest riparian veg.
Water	water	water

Table 5

Walnut Creek Land Use Comparison
UCD LANDSAT vs. CONVENTIONAL*

	Acres % Row % Col % Total	CONVENTIONAL RES	 COM/IND	 QUARRY	 CROP/PASTURE /RANGE	 FOREST	 WATER	ROW TOTAL
UCD LANDSAT	RES	3801 41.6 59.8 10.4	1098 12.0 31.6 3.0	225 2.5 22.0 0.6	3147 34.4 19.1 8.6	859 9.4 9.4 2.3	6 0.1 9.5 0.0	9136 100.0 25.0 25.0
	COM/IND	471 25.3 7.4 1.3	816 43.8 23.5 2.2	130 7.0 12.7 0.4	366 19.7 2.2 1.0	78 4.2 0.9 0.2	0 0.0 0.0 0.0	1861 100.0 5.1 5.1
	QUARRY	13 5.8 0.2 0.0	61 27.4 1.8 0.2	111 49.8 10.9 0.3	17 7.6 0.1 0.0	21 9.4 0.2 0.1	0 0.0 0.0 0.0	223 100.0 0.6 0.6
	CROP/PASTURE	1581 10.3 24.9 4.3	1106 7.2 31.8 3.0	313 2.0 30.7 0.9	9324 60.9 56.4 25.5	2947 19.3 32.2 8.1	28 0.2 44.4 0.1	15229 100.0 41.8 41.8
	FOREST/RANGE	493 4.9 7.8 1.3	361 3.6 10.4 1.0	234 2.3 22.9 0.6	3655 36.6 22.1 10.0	5233 52.4 57.2 14.3	13 0.1 20.6 0.0	9989 100.0 27.3 27.3
	WATER	0 0.0 0.0 0.0	31 44.3 0.9 0.1	8 11.4 0.8 0.0	9 12.9 0.1 0.0	6 8.6 0.1 0.0	16 22.9 25.4 0.0	70 100.0 0.2 0.2
	COLUMN TOTAL	6359 17.4 100.0 17.4	3473 9.5 100.0 9.5	1021 2.8 100.0 2.8	16518 45.2 100.0 45.2	9144 25.0 100.0 25.0	63 0.2 100.0 0.2	36578 100.0 100.0 100.0

* Note: See page 15 of text for explanation of table structure.

The above comparison at the grid cell level is nearly equivalent to a comparison at the LANDSAT pixel scale. An alternative comparison, less sensitive to geometric correction and resampling errors, is of the major land use categories at the watershed level. Looking at the total percent classified as (a) residential, (b) commercial/industrial, and (c) cropland/pasture/forest/rangeland by conventional and LANDSAT shows a difference of 7.6%, -4.4% and -1.1%, respectively. The average absolute difference for the major land use categories is 4.4%.

Rowlett Creek

Rowlett Creek is a 137 square mile, predominately rural watershed located near Dallas, Texas. Rowlett Creek was classified from LANDSAT data by UCD staff and the results reported by Algazi (1978). HEC entered the LANDSAT classification into a grid cell data bank (previously created by the Fort Worth District) and compared it with conventional land use. Specifications on the imagery, ground truth, and conventional land use are given below.

LANDSAT Imagery:

- 3 May 1976, ID# 2467-16185.

Ground Truth:

- NASA high-altitude color infrared aerial photography, May 1972, scale = 1:102,000.
- USGS 7-1/2-minute topographic maps, photorevised 1968 and 1973, scale = 1:24,000.

Conventional Land Use:

- Interpreted from low-altitude black/white aerial photography, March 1976, scale = 1:24,000.

Area tables for the LANDSAT and conventional classifications appear as Tables 6 and 7, respectively. Corresponding line printer maps[1] are given in Figures 6 and 7. Land use category mapping from the larger number of conventional classes into the LANDSAT classes is listed in Table 8. Finally, Table 9 contains the LANDSAT - conventional land use comparison results.

[1] Common printer symbols were used for the same land use category in both classifications. This practice was continued for all similar pairs of land use maps presented in following sections.

Table 6

Rowlett Creek LANDSAT Land Use
Area Table

Land Use Category	Acres	%
Agricultural	62,370	70.8
Natural Vegetation	4,659	5.3
Residential	17,613	20.0
Commercial/Industrial	3,409	3.9
	88,051	100.0

Table 7

Rowlett Creek Conventional Land Use
Area Table

Land Use Category	Acres	%
Low density residential	1,200	1.4
Medium density residential	7,810	8.9
High density residential	92	0.1
Multifamily residential	201	0.2
Mobile home parks	84	0.1
Developing	3,554	4.0
Central Business District	128	0.1
Strip Commercial	346	0.4
Shopping Centers	167	0.2
Institutional - School, Churches	716	0.8
Industrial	820	0.9
Transportation; Major Highways	1,473	1.7
Communication	5	0.0
Public Utilities	168	0.2
Strip Settlement	199	0.2
Parks & Developed Open Space	1,067	1.2
Cropland	31,241	35.5
Grassland	30,985	35.2
Confined Feeding	75	0.1
Barren Land, Gravel Pits	738	0.8
Woodlands, Forest	6,869	7.8
Water Bodies	116	0.1
	88,054	99.9

Two rows in Table 9 are blank. Although identified as target land use classes, UCD staff were "unable to make any assignments to the categories developed open space and water bodies" (Algazi, 1978) because very few land areas representing these categories could be located on the aerial photographs. As a summary measure of accuracy, the diagonal summation shows

Figure 6
Rowlett Creek
LANDSAT Land Use

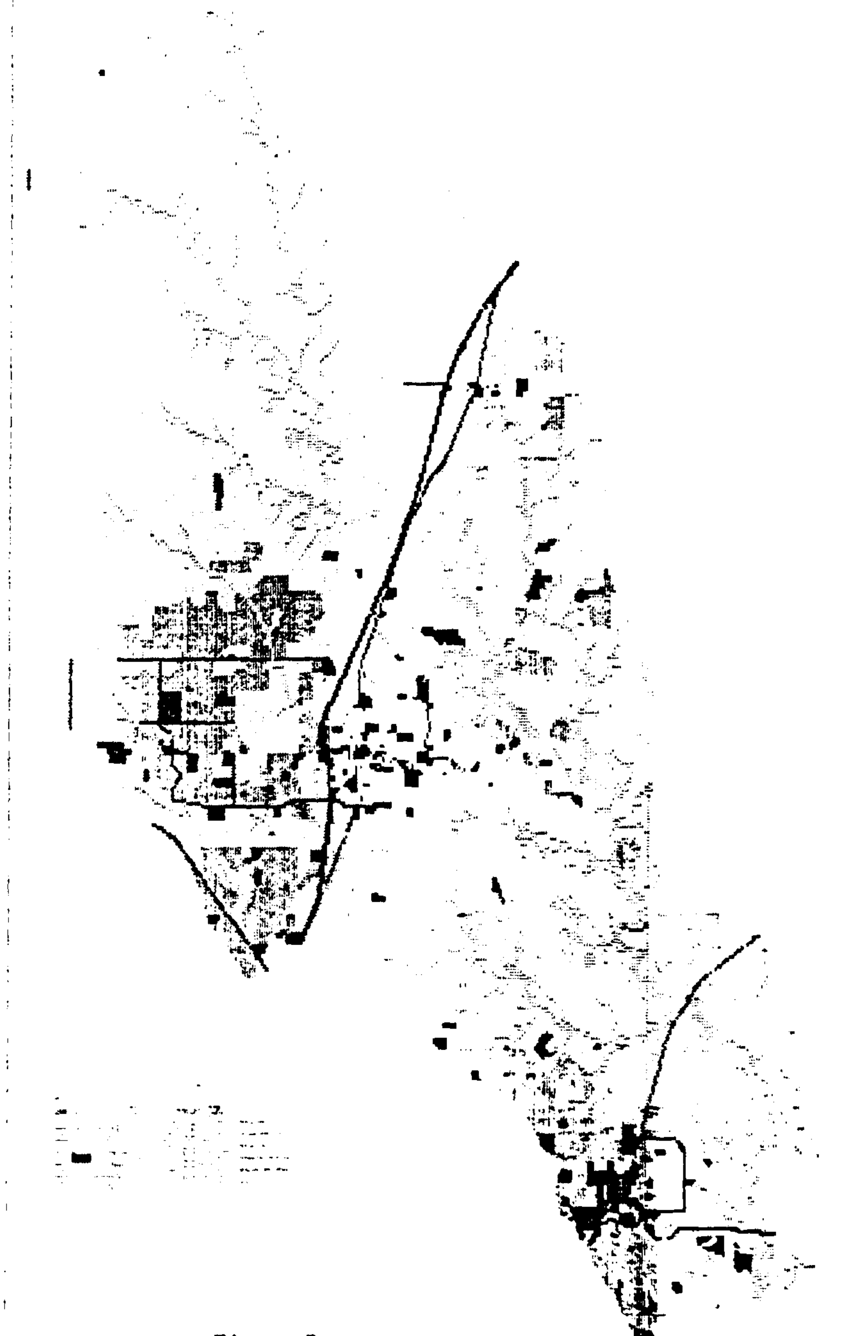


Figure 7
Rowlett Creek
Conventional Land Use

Table 8

Rowlett Creek
Land Use Category Mapping

Conventional Land Use	LANDSAT Land Use
Low Density Residential Medium Density Residential High Density Residential Multifamily Residential Mobile Home Parks Developing	Residential
Central Business District Strip Commercial Shopping Centers Institutional - School, Churches Industrial Transportation, Major Highways Communication Public Utilities Strip Settlement	Commercial/Industrial
Cropland Grassland Confined Feeding Barren Land, Gravel Pits	Agricultural
Woodlands, Forest	Natural Vegetation
Parks and Developed Open Space	Developed Open Space
Water Bodies	Water

Table 9

Rowlett Creek Land Use Comparison
LANDSAT vs. Conventional*

	Acres % Row % Col % Total	CONVENTIONAL RES	 COM/IND	 AGRIC	 NAT VEG	 DEP OPN SP	 WATER	ROW TOTAL
	RES	7431 42.2 57.4 8.4	1706 9.7 42.4 1.9	6637 37.7 10.5 7.5	1401 8.0 20.4 1.6	409 2.3 38.4 0.5	30 0.2 25.7 0.0	17613 100.0 20.0 20.0
	COM/IND	957 28.1 7.4 1.1	312 9.1 7.7 0.4	1940 56.9 3.1 2.2	153 4.5 2.2 0.2	48 1.4 4.5 0.1	0 0.0 0.0 0.0	3410 100.0 3.9 3.9
LANDSAT	AGRIC	4340 7.0 33.5 4.9	1898 3.0 47.2 2.2	50877 81.6 80.7 57.8	4631 7.4 67.4 5.3	545 0.9 51.5 0.6	79 0.1 68.3 0.1	62370 100.0 70.8 70.8
	NAT VEG	212 4.5 1.6 0.2	107 2.3 2.7 0.1	3585 76.9 5.7 4.1	684 14.7 10.0 0.8	64 1.4 6.0 0.1	7 0.1 5.9 0.0	4659 100.0 5.3 5.3
	DEV OPN SP							
	WATER							
	COLUMN TOTAL	12940 14.7 100.0 14.7	4022 4.6 100.0 4.6	63038 71.6 100.0 71.6	6869 7.8 100.0 7.8	1067 1.2 100.0 1.2	116 0.1 100.0 0.1	88052 100.0 100.0 100.0

* Note: See page 15 of text for explanation of table structure.

67.4% of the grid cells "correctly" classified by LANDSAT. The four major land use categories are (a) residential, (b) commercial/industrial, (c) agricultural, and (d) natural vegetation; corresponding percent differences between conventional and LANDSAT are 5.3%, -0.7%, -0.8%, and -2.5%, respectively. Average absolute error for the major land use classes is 2.3%.

Pennypack Creek

Pennypack Creek is a 55.8 square mile basin that drains part of Philadelphia, Pennsylvania. UCD staff determined land use from LANDSAT (Algazi, 1978) and HEC entered the classification in a grid cell data bank (constructed by the Philadelphia District) and made the land use comparison. Details of the LANDSAT imagery, ground truth data, and conventional land use are listed below.

LANDSAT Imagery:

- 19 April 1976, ID# 2453-14565.

Ground Truth:

- NASA high altitude color infrared aerial photography, 5 Feb 1974, scale = 1:131,000.
- NASA high altitude color infrared aerial photography, 28 Aug 1975, scale = 1:57,000.
- USGS 7-1/2-minute topographic maps, photorevised 1973, scale = 1:24,000.

Conventional Land Use:

- 1975 tax maps for Bucks County, scale: 1" = 400'.
- 1976 tax maps for Philadelphia, scale: 1" = 200'.
- 1975 aerial photography for Montgomery County, scale: 1" = 400'.
- Entire basin verified against 1977 aerial photography, scale: 1" = 400'.

Area tables for LANDSAT and conventional classifications are shown in Tables 10 and 11, respectively. Corresponding line printer maps are given in Figures 8 and 9. Land use category mapping between the two classifications is listed in Table 12, and grid cell comparison results in Table 13.

Table 10

Pennypack Creek LANDSAT Land Use
Area Table

Land Use Category	Acres	%
Natural vegetation	5,660	15.9
Pasture	1,884	5.3
Agriculture	1,076	3.0
Developed Open Space	1,763	4.9
Residential	24,405	68.4
Light Industry	182	0.5
Intermediate Industry	457	1.3
Heavy Industry	165	0.7
Water	0	0.0
	35,693	100.0

Table 11

Pennypack Creek Conventional Land Use
Area Table

Land Use Category	Acres	%
Forest and Undeveloped	7,499	21.0
Agriculture	3,341	9.4
Recreation and Cultural	1,832	5.1
Single - High Value	6,186	17.3
Single - Low Value	6,747	18.9
Twin - High Value	2,343	6.6
Twin - Medium Value	116	0.3
Twin - Low Value	54	0.2
Apartments - High Value	705	2.0
Apartments - Low Value	781	2.2
Community Services - High Value	24	0.1
Community Services - Low Value	1,296	3.6
Light Industry	619	1.7
Communications and Utilities	154	0.4
Military	1	0.0
Commercial - High Value	861	2.4
Commercial - Low Value	981	2.7
Mining	35	0.1
Heavy Industry	922	2.6
Transportation	910	2.5
Water Bodies	289	0.8
	35,693	99.9

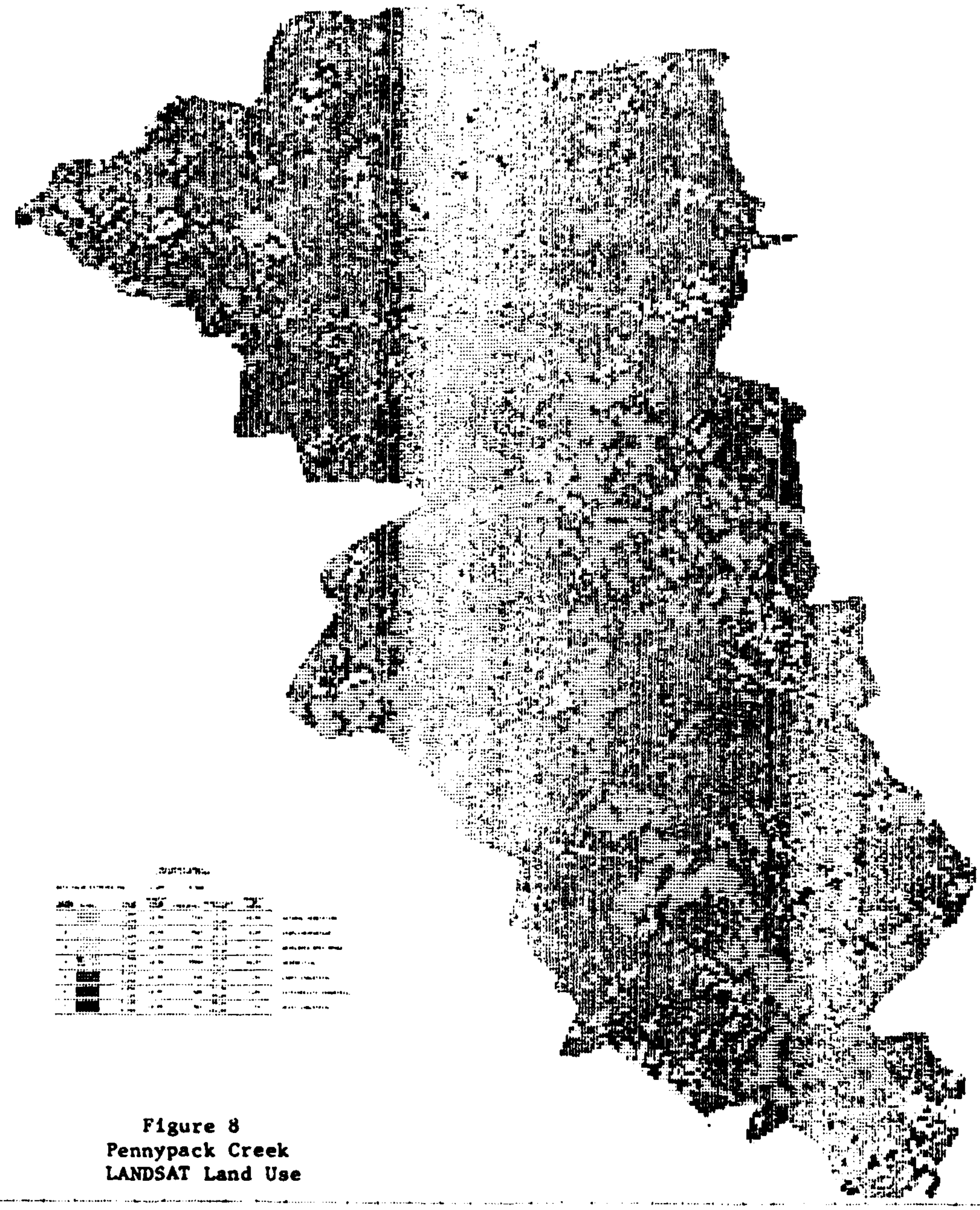


Figure 8
Pennypack Creek
LANDSAT Land Use

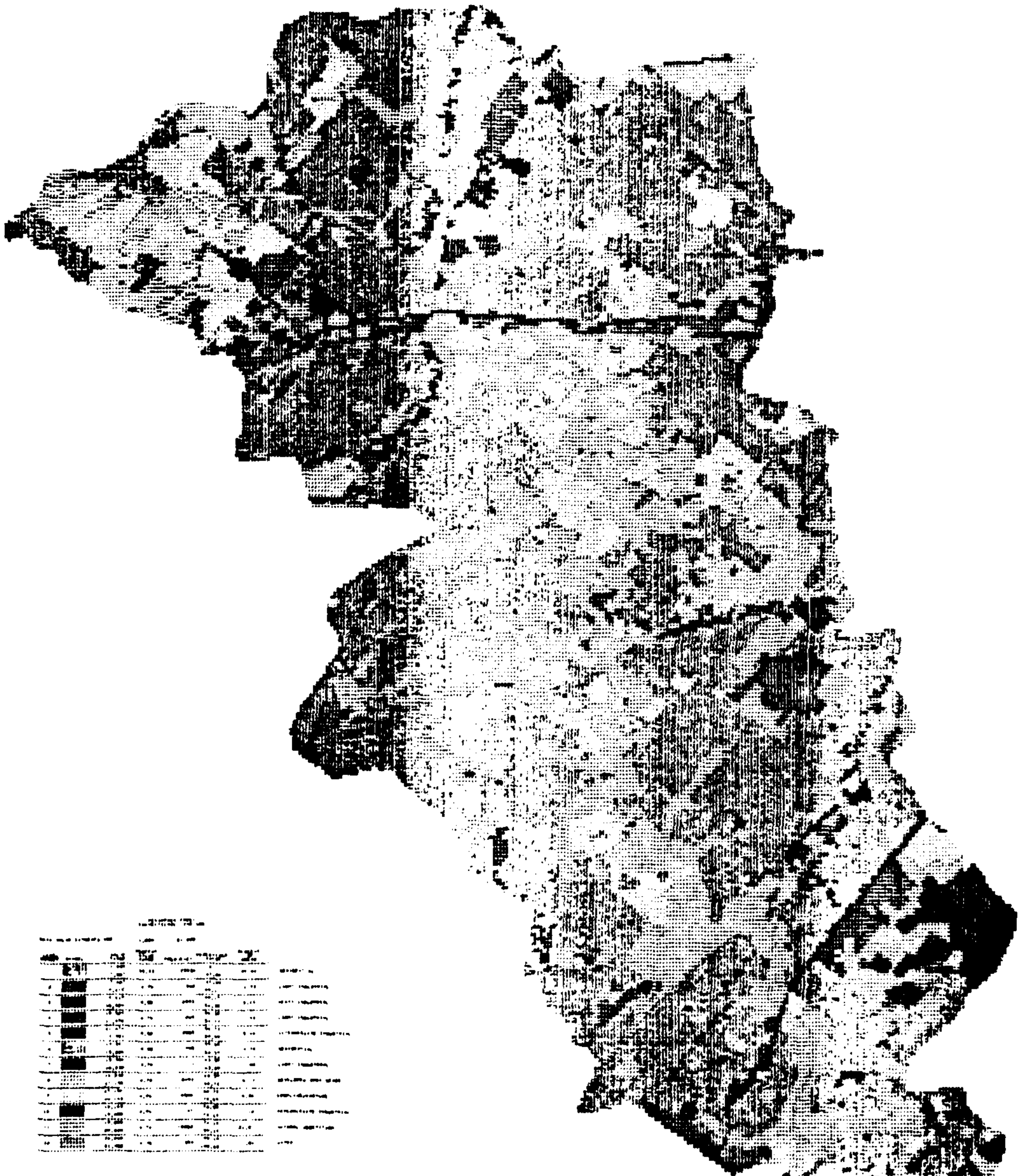


Figure 9
Pennypack Creek
Conventional Land Use

Table 12

Pennypack Creek
Land Use Category Mapping

Conventional Land Use	LANDSAT
Forest and Undeveloped	Natural Vegetation
Agriculture	Pasture Agriculture
Recreation and Cultural	Developed Open Space
Single - High Value Single - Low Value Twin - High Value Twin - Medium Value Twin - Low Value Apartments - High Value Apartments - Low Value Community Services, - High Value Community Services - Low Value	Residential
Light Industry Communications and Utilities Military	Light Industry
Commercial - High Value Commercial - Low Value Mining	Intermediate Industry
Heavy Industry Transportation	Heavy Industry
Water Bodies	Water

Table 13

Pennypack Creek Land Use Comparison
LANDSAT vs. Conventional*

	Acres % Row % Col % Total	CONVENTIONAL								
		NAT VEG	AGRIC	DEV OP SP	RES	LT IND	INT IND	HVY IND	WATER	ROW TOTAL
LANDSAT	NAT VEG	2646 46.7 35.3 7.4	343 6.1 10.3 1.0	290 5.1 15.8 0.8	1999 35.3 11.0 5.6	37 0.7 4.8 0.1	88 1.6 4.7 0.2	85 1.5 4.6 0.2	174 3.1 60.2 0.5	5660 100.0 15.9 15.9
	AGRIC	395 13.3 5.2 1.1	436 14.7 13.1 1.2	102 3.4 5.5 0.3	944 31.9 5.2 2.6	215 7.3 27.8 0.6	461 15.6 24.6 1.3	397 13.4 21.7 1.1	10 0.3 3.5 0.0	2960 100.0 8.3 8.3
	DEV OP SP	296 16.8 3.9 0.8	498 28.2 14.9 1.4	409 23.2 22.3 1.1	505 28.6 2.8 1.4	19 1.1 2.5 0.1	18 1.0 1.0 0.1	11 0.6 0.6 0.0	7 0.4 2.4 0.0	1763 100.0 4.9 4.9
	RES	4023 16.5 53.7 11.3	1900 7.8 56.9 5.3	962 3.9 52.5 2.7	14564 59.7 79.8 40.8	457 1.9 59.1 1.3	1183 4.8 63.1 3.3	1223 5.0 66.8 3.4	92 0.4 31.8 0.3	24405 100.0 68.4 68.4
	LT IND	35 19.2 0.5 0.1	33 18.1 1.0 0.1	13 7.1 0.7 0.0	32 17.6 0.2 0.1	19 10.4 2.5 0.1	23 12.6 1.2 0.1	27 14.8 1.5 0.1	0 0.0 0.0 0.0	182 100.0 0.5 0.5
	INT IND	71 15.5 1.0 0.2	131 28.7 3.9 0.4	46 10.1 2.5 0.1	182 39.8 1.0 0.5	13 2.8 1.7 0.0	7 1.5 0.4 0.0	7 1.5 0.4 0.0	0 0.0 0.0 0.0	457 100.0 1.3 1.3
	HVY IND	32 12.1 0.4 0.0	2 0.8 0.1 0.0	11 4.2 0.6 0.0	25 9.4 0.1 0.1	13 4.9 1.7 0.0	95 35.8 5.1 0.3	82 30.9 4.5 0.2	6 2.3 2.1 0.0	265 100.0 0.7 0.7
	WATER									
	COLUMN TOTAL	7499 21.0 100.0 21.0	3341 9.4 100.0 9.4	1832 5.1 100.0 5.1	18251 51.1 100.0 51.1	773 2.2 100.0 2.2	1876 5.3 100.0 5.3	1832 5.1 100.0 5.1	289 0.8 100.0 0.8	35693 100.0 100.0 100.0

* Note: See page 15 of text for explanation of table structure.

The most noticable conflicts in Table 13 occur between natural vegetation and residential, and between agricultural and residential. Diagonal summation shows 50.8% of the watershed "correctly" classified by LANDSAT. The major land use categories are (a) natural vegetation, (b) agricultural, (c) developed open space, (d) residential, and (e) industrial; their corresponding percent differences between conventional and LANDSAT are -5.1%, -1.1%, -0.2%, 17.3%, and -10.1%, respectively. Average absolute error for the major categories is 6.8%.

Castro Valley

Castro Valley is a small urban watershed (drainage area = 5.7 mi^2) located in the San Francisco Bay area. LANDSAT land use had been determined by UCD (Algazi, 1977a) and entered into a grid cell data bank by HEC. The conventional land use classification, and the data bank itself, were determined by HEC staff for use in Corps of Engineers training activities. Sources of data for LANDSAT analysis, ground truth, and conventional land use are listed below.

LANDSAT Imagery:

- 30 Jan 1975, ID# 1921-18022.

Ground Truth:

- NASA high-altitude color infrared aerial photography, date and scale unknown.

- USGS 7-1/2-minute topographic map, photorevised 1973, scale = 1:24,000.

Conventional Land Use:

- USGS 7-1/2-minute topographic map, photorevised 1973, scale = 1:24,000.

- Alameda County Flood Control and Water Conservation District, Castro Valley Drainage Map, date unknown, scale: 1" = 500'.

Area tables for LANDSAT and conventional appear together in Table 14, and line printer maps are given separately in Figures 10 and 11. Only a small amount of mapping conventional categories into LANDSAT categories was necessary, as shown in Table 15. The grid cell comparison of land use is shown in Table 16.

Table 14

Castro Valley
Area Tables

LANDSAT Land Use	Acres	%
Natural Vegetation	852	23.3
Developed Open Space	25	0.7
Residential	2,151	58.9
Commercial/Industrial	627	17.2
	3,655	100.1

Conventional Land Use	Acres	%
Natural Vegetation	617	16.9
Developed Open Space	165	4.5
Low Density Residential	520	14.2
Med Density Residential	1,763	48.2
High Density Residential	301	8.2
Commercial	171	4.7
Institutional	109	3.0
Water	9	0.3
	3,655	100.0

Table 15

Castro Valley
Land Use Category Mapping

Conventional Land Use	LANDSAT Land Use
Natural Vegetation	Natural Vegetation
Developed Open Space	Developed Open Space
Low Density Residential Med Density Residential High Density Residential	Residential
Commercial Institutional	Commercial/Industrial
Water	Water

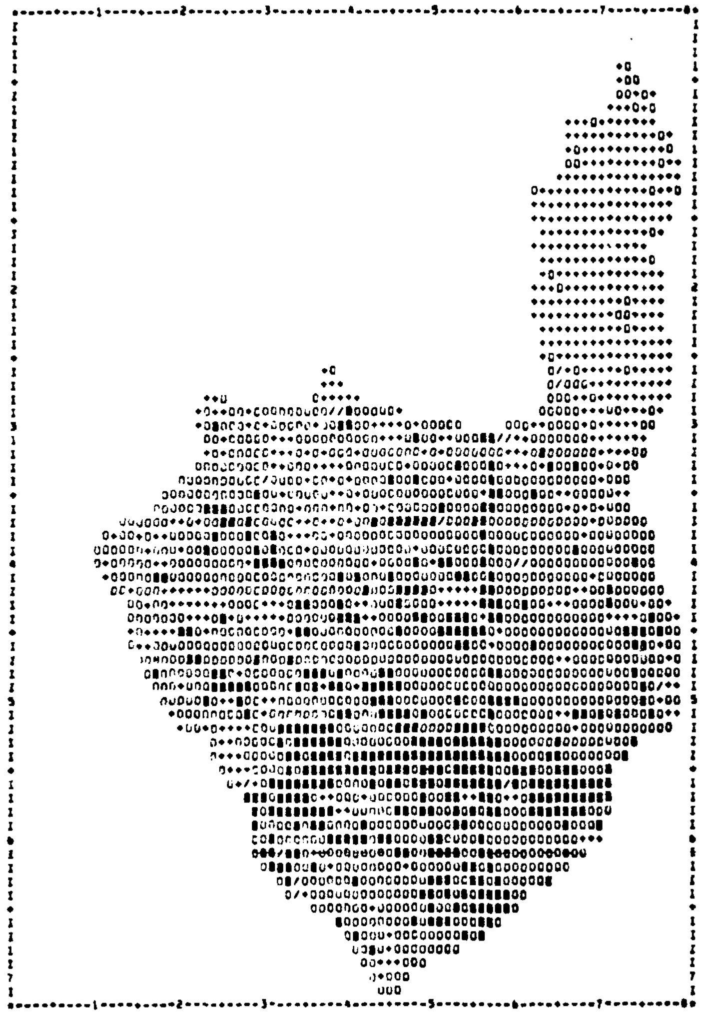


Figure 10

CASTRO VALLEY
LANDSAT LAND COVER

DATA VALUE EXTREMES ARE 1,000 4,000

LEVEL NUMBER	SYMBOL	VALUE RANGE	PERCENT VALUE RANGE	FREQUENCY	PERCENTILE RANGE	PERCENT OF AREAS	
1	++++++++	1,000 – 1,750	25.00	557	0. – 23.32	23.32	NATURAL VEGETATION
2	////////	1,750 – 2,500	25.00	16	23.32 – 23.98	.67	DEVELOPED OPEN SPACE
3	00000000	2,500 – 3,250	25.00	1406	23.98 – 82.84	58.85	RESIDENTIAL
4	■■■■■■■■	3,250 – 4,000	25.00	410	82.84 – 100.00	17.16	COMMERCIAL/INDUSTRIAL

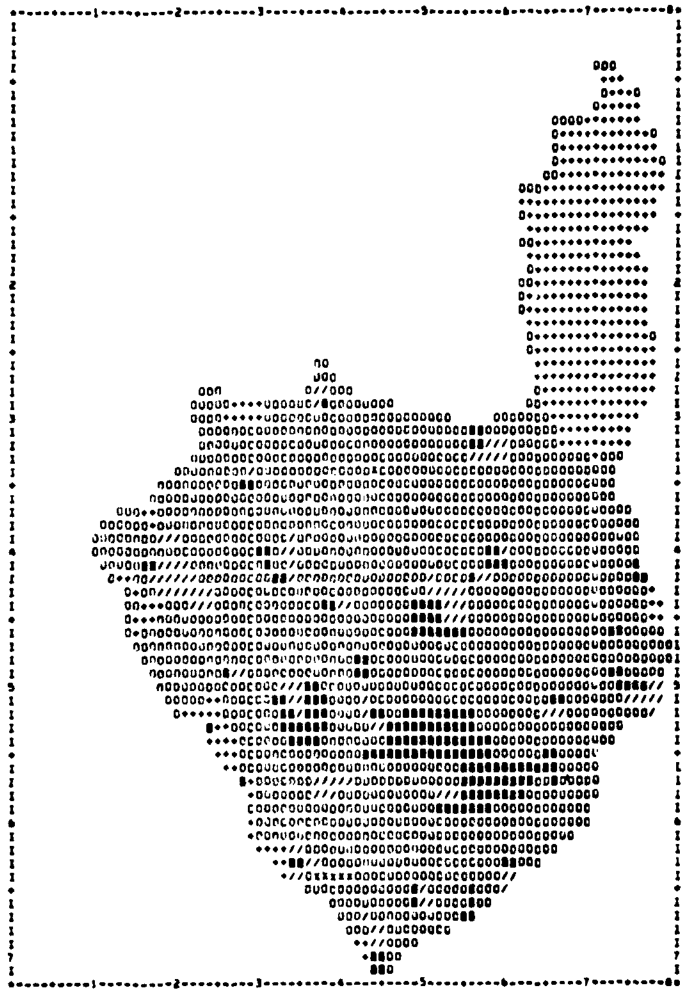


Figure 11

CASTRO VALLEY
CONVENTIONAL (5 CATEGORIES) LAND USE

DATA VALUE EXTREMES ARE 1,000 5,000

LEVEL NUMBER	SYMBOL	VALUE RANGE	PERCENT VALUE RANGE	FREQUENCY	PERCENTILE RANGE	PERCENT OF AREAS	
1	++++++++	1,000 1,800	20,00	403	0. 16,85	16,85	NATURAL VEGETATION
2	////////	1,800 2,600	20,00	108	16,85 21,36	4,52	DEVELOPED OPEN SPACE
3	00000000	2,600 3,400	20,00	1692	21,36 92,10	70,74	RESIDENTIAL
4	■■■■■■■■	3,400 4,200	20,00	183	92,10 99,75	7,65	COMMERCIAL/INDUSTRIAL
5	XXXXXXXX	4,200 5,000	20,00	6	99,75 100,00	,25	WATER

Table 16

Castro Valley Land Use Comparison
LANDSAT vs. Conventional*

	Acres % Row % Col % Total	CONVENTIONAL NAT VEG	 DEV OP SP	 RES	 COM/IND	 WATER	ROW TOTAL
LANDSAT	NAT VEG	476 55.8 77.2 13.0	55 6.5 33.3 1.5	312 36.6 12.1 8.5	9 1.1 3.3 0.3	0 0.0 0.0 0.0	852 100.0 23.3 23.3
	DEV OP SP	3 12.5 0.5 0.1	3 12.5 1.9 0.1	14 56.3 0.5 0.4	5 18.8 1.6 0.1	0 0.0 0.0 0.0	25 100.0 0.7 0.7
	RES	129 6.0 20.8 3.5	77 3.6 46.3 2.1	1821 84.6 70.5 49.8	116 5.4 41.5 3.2	9 0.4 100.0 0.3	2151 100.0 58.9 58.9
	COM/IND	9 1.5 1.5 0.3	31 4.9 18.5 0.8	438 69.8 16.9 12.0	150 23.9 53.6 4.1	0 0.0 0.0 0.0	627 100.0 17.2 17.2
	WATER						
	COLUMN TOTAL	617 16.9 100.0 16.9	165 4.5 100.0 4.5	2584 70.7 100.0 70.7	280 7.7 100.0 7.7	9 0.3 100.0 0.3	3655 100.0 100.0 100.0

*Note: See page 15 of text for explanation of table structures.

The largest conflicts in Table 16 occur between the conventional residential class and LANDSAT natural vegetation, developed open space, and commercial/industrial categories. Diagonal summation shows 67.0% of the watershed "correctly" classified by LANDSAT. The four major classes in Table 16 are (a) natural vegetation, (b) developed open space, (c) residential. and (d) commercial/industrial; LANDSAT - conventional differences are 6.4%, -3.8%, -11.8%, and 9.5%, respectively. Average absolute error for the major land use categories is 7.9%.

Summary

Results from the comparison of LANDSAT and conventional land use for four watersheds (Walnut Creek, Rowlett Creek, Pennnypack Creek, and Castro Valley) have been presented. A summary of the comparison at the grid cell level is given in Table 17, and at the watershed level in Table 18. A general pattern in the error evaluation is apparent: individual grid cells were incorrectly classified by LANDSAT 1/3 of the time, whereas aggregation of grid cells over the entire watershed showed misclassification of the major land use categories averaging 2 to 8%.

Table 17

Accuracy of Landsat Land Use Classification
Grid Cell Level

WATERSHED	Drainage Area (mi^2)	ACCURACY (%)
Walnut	55	52.7/70.8
Rowlett	137	67.4
Pennypack	56	50.8
Castro Valley	5.7	67.0
	Avg.	= 61.7

COMMERCIAL LANDSAT CLASSIFICATION

In addition to learning and using the UCD Procedure, HEC staff had the opportunity to participate in the LANDSAT land use classification operations at two commercial firms: The Bendix Corporation and Battelle Pacific Northwest Laboratories[1]. Having first-hand knowledge of what is available commercially would allow a more comprehensive evaluation of the UCD Procedure.

[1] Battelle Pacific Northwest Laboratories
Battelle Boulevard
Richmond, Washington 99352

Table 18

LANDSAT Land Use Classification Error (%)
Watershed Level

WALNUT	Conv	LANDSAT	diff
Res	17.4	25.0	7.6
Com/Ind	9.5	5.1	-4.4
Crop/Pasture/ Forest/Range	70.2	69.1	-1.1
		Avg. Abs =	4.4

ROWLETT	Conv	LANDSAT	diff
Res	14.7	20.0	5.3
Com/Ind	4.6	3.9	-0.7
Ag	71.6	70.8	-0.8
Nat Veg	7.8	5.3	-2.5
		Avg. Abs =	2.3

PENNYPACK	Conv	LANDSAT	diff
Nat Veg	21.0	15.9	-5.1
Ag	9.4	8.3	-1.1
DevOpSp	5.1	4.9	-0.2
Res	51.1	68.4	17.3
Ind	12.6	2.5	-10.1
		Avg. Abs =	6.8

CASTRO VLY	Conv	LANDSAT	diff
Nat Veg	16.9	23.3	6.4
DevOpSp	4.5	0.7	-3.8
Res	70.7	58.9	-11.8
Com/Ind	7.7	17.2	9.5
		Avg. Abs =	7.9

Bendix

HEC staff and the UCD principal investigator visited the Bendix facilities in Ann Arbor, Michigan. (Bendix operations have since been taken over by the Environmental Research Institute of Michigan[1].) Land use for a 1,064 square mile area was classified from LANDSAT imagery by selecting representative training sites throughout the San Francisco Bay area. The final classification was checked carefully in Castro Valley.

Output products included color-coded land use maps and a resampled computer tape[2] for selected portions of the classified area. The land use classification of Castro Valley was compared (at the watershed level) with other published commercial classifications of the basin in HEC's contribution to an ASVT interim report (Salmonson, 1977).

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[1] ERIM
Box 8618, Ann Arbor,
Michigan 48107

[2] HEC has been unable to read the resampled tape, as it was not constructed to contract specifications.

Battelle

HEC and Fort Worth District staff participated in the LANDSAT classification of Walnut Creek at Battelle's Pacific Northwest Laboratories in Richland, Washington. Training sites were selected from the same LANDSAT scene that had been previously analyzed with the UCD Procedure at HEC (as described earlier in this report in the Walnut Creek discussion). The final classification was identified in a color-coded land use map, Figure 12, and on a resampled computer tape[1]. Table 19 contains the acreage[2] and percent distribution of Battelle's LANDSAT land use. The mapping of the Battelle categories into conventional and UCD LANDSAT categories is shown in Table 4. Figure 13 is a line printer map of Battelle's land use.

The resampled Battelle tape was entered into the Walnut Creek grid cell data bank. Comparisons between Battelle LANDSAT and conventional, and between Battelle LANDSAT and UCD LANDSAT are shown in Tables 20 and 21, respectively. Summary measures of comparison are provided in Table 22.

Table 19

Walnut Creek Battelle LANDSAT Land Use
Area Table

Land Use Category	Acres	%
Barren Land	1,200	3.5
Quarry	217	0.6
Industrial/Commerical	611	1.8
Residential	6,513	18.8
Cropland/Pasture	9,536	27.5
Rangeland	8,597	24.8
Riparian Vegetation	4,663	13.4
Forest	1,630	4.7
Water	54	0.2
Transportation	1,676	4.8
	34,697	100.1

[1] After the tape had been provided to HEC, it was discovered that the wrong corner grid cell was used in the resampling. A corrected tape is reported to be forthcoming from Battelle. All land use comparisons of the Battelle classification will be affected by this known resampling error.

[2] The total classified land area listed on Battelle's color-coded map was 35,869 acres (56.05 sq. mi.). When the Battelle resampled file was entered into the Walnut Creek grid cell data bank only 34,697 acres (54.21 sq. mi.) were located within the geographically correct watershed boundary, the latter being defined in the data bank as containing 36,574 acres (57.15 sq. mi.). This discrepancy was probably due to the resampling problems described in the footnote above.

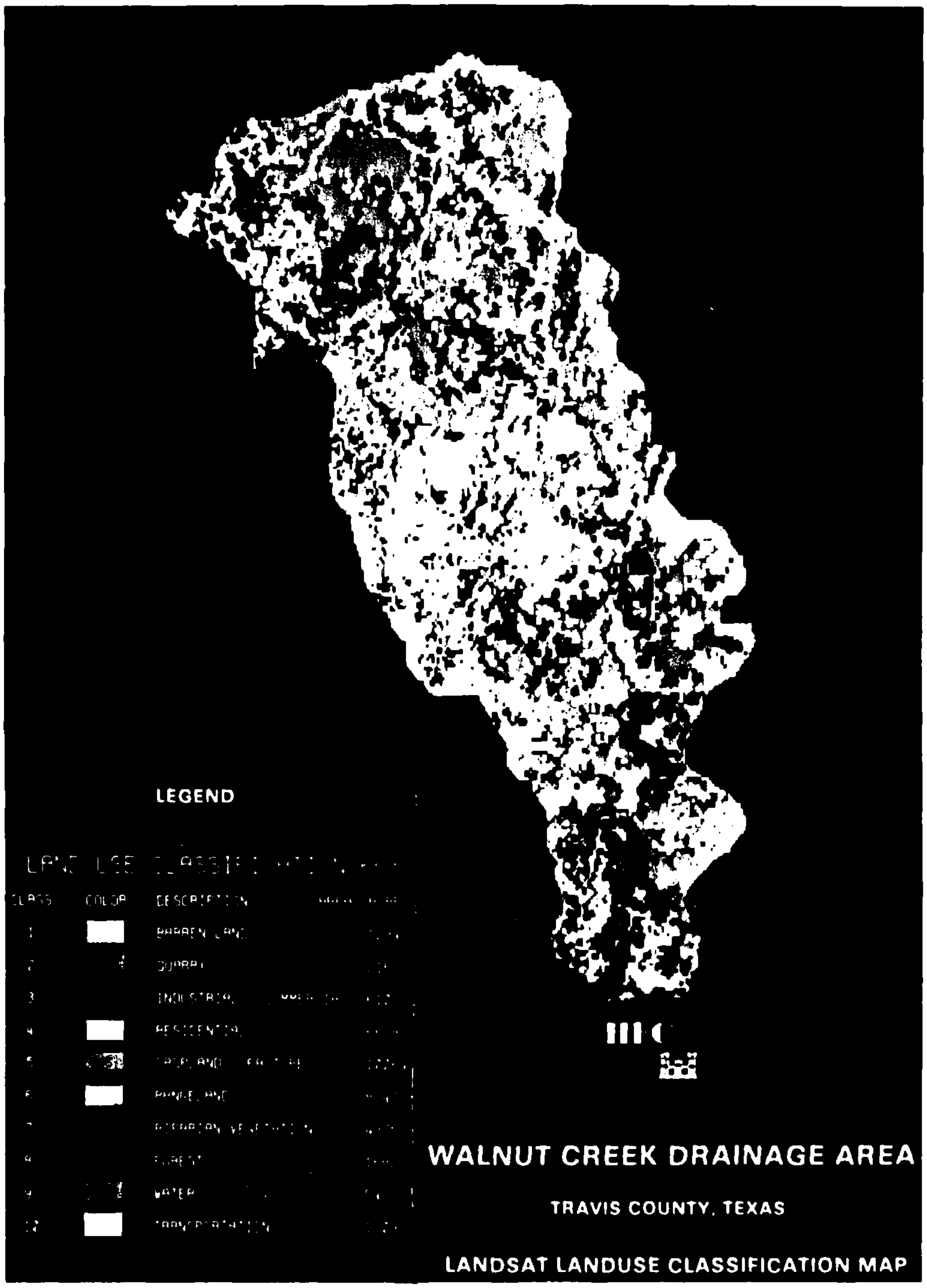

Figure 12

Walnut Creek
Battelle LANDSAT Land Use

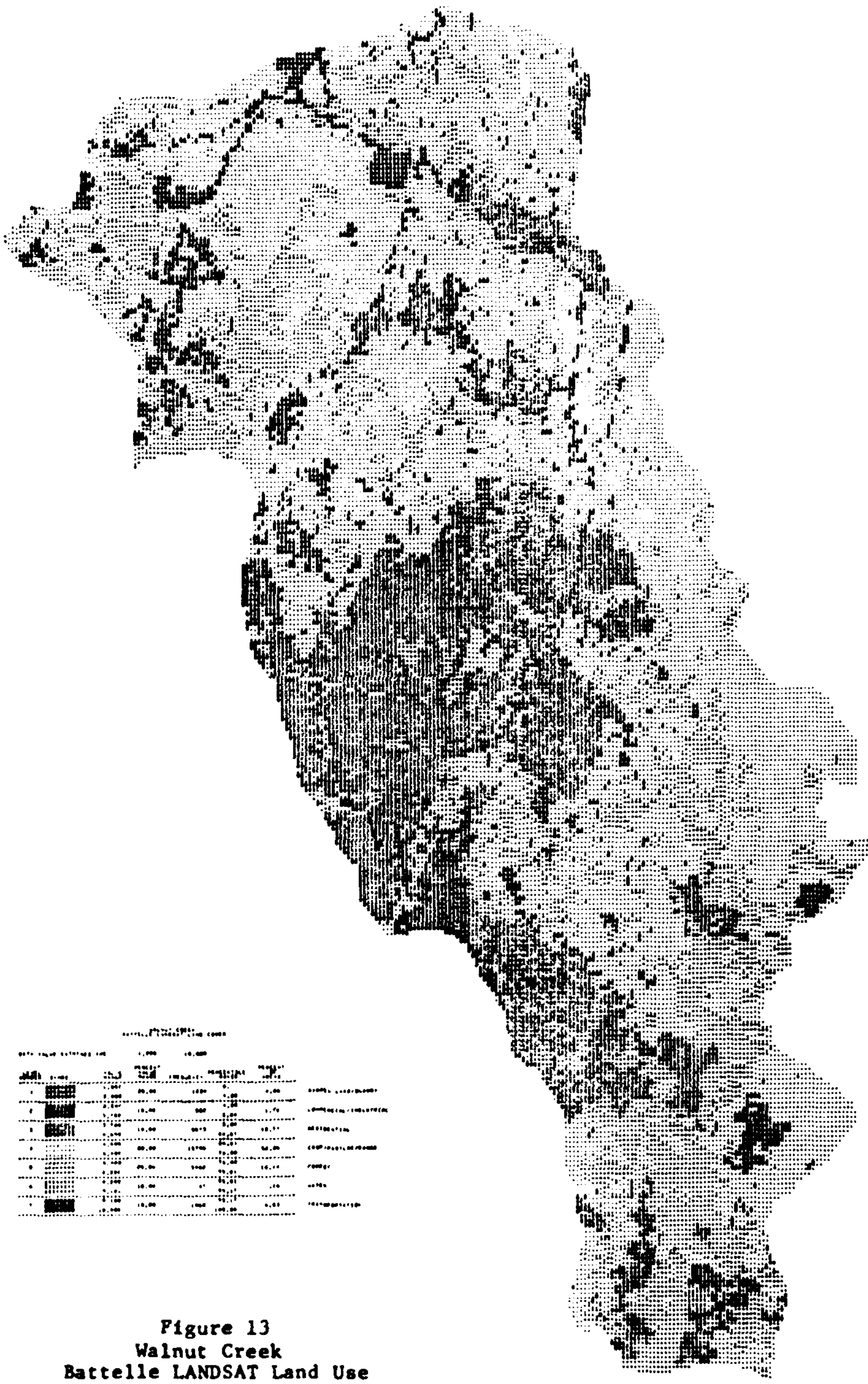

Figure 13
Walnut Creek
Battelle LANDSAT Land Use

Table 20

Walnut Creek Land Use Comparison
Battelle LANDSAT vs. Conventional*

	Acres % Row % Col % Total	CONVENTIONAL RES	COM/IND	QUARRY	CROP/PASTURE /RANGE	FOREST	WATER	ROW TOTAL
BATTELLE LANDSAT	RES	2723 41.8 45.6 7.8	976 15.0 31.6 2.8	70 1.1 7.2 0.2	1969 30.2 12.4 5.7	763 11.7 8.7 2.2	12 0.2 19.0 0.0	6513 100.0 18.8 18.8
	COM/IND	661 28.9 11.1 1.9	336 14.7 10.9 1.0	79 3.5 8.1 0.2	890 38.9 5.6 2.6	319 14.0 3.6 0.9	1 0.0 1.6 0.0	2286 100.0 6.6 6.6
	QUARRY	212 15.0 3.5 0.6	160 11.3 5.2 0.5	111 7.8 11.3 0.3	614 43.4 3.9 1.8	319 22.5 3.6 0.9	0 0.0 0.0 0.0	1416 100.0 4.1 4.1
	CROP/PASTURE/ RANGE	1720 9.5 28.8 5.0	1137 6.3 36.8 3.3	517 2.9 52.9 1.5	9803 54.1 61.8 28.3	4922 27.1 56.3 14.2	37 0.2 58.7 0.1	18136 100.0 52.3 52.3
	FOREST	636 10.1 10.6 1.8	464 7.4 15.0 1.3	201 3.2 20.6 0.6	2572 40.9 16.2 7.4	2410 38.3 27.6 6.9	12 0.2 19.0 0.0	6295 100.0 18.1 18.1
	WATER	23 42.6 0.4 0.1	13 24.1 0.4 0.0	0 0.0 0.0 0.0	8 14.8 0.1 0.0	9 16.7 0.1 0.0	1 1.9 1.6 0.0	54 100.0 0.2 0.2
	COLUMN TOTAL	5975 17.2 100.0 17.2	3086 8.9 100.0 8.9	978 2.8 100.0 2.8	15856 45.7 100.0 45.7	8742 25.2 100.0 25.2	63 0.2 100.0 0.2	34700 100.0 100.0 100.0

* Note: See page 15 of text for explanation of table structure.

Table 21

Walnut Creek Land Use Comparison
Battelle Landsat vs. UCD LANDSAT*

		Acres % Row % Col % Total	UCD LANDSAT RES	COM/IND	QUARRY	CROP/PASTURE	FOREST/ RANGE	WATER	ROW TOTAL
BATTELLE LANDSAT	RES	Acres	3218	607	32	1839	812	5	6513
		% Row	49.4	9.3	0.5	28.2	12.5	0.1	100.0
		% Col	36.8	36.1	15.8	12.6	8.6	7.2	18.8
		% Total	9.3	1.7	0.1	5.3	2.3	0.0	18.8
	COM/IND	Acres	816	212	15	834	395	15	2287
		% Row	35.7	9.3	0.7	36.5	17.3	0.7	100.0
		% Col	9.3	12.6	7.4	5.7	4.2	21.7	6.6
		% Total	2.4	0.6	0.0	2.4	1.1	0.0	6.6
	QUARRY	Acres	392	116	17	566	325	1	1417
		% Row	27.7	8.2	1.2	39.9	22.9	0.1	100.0
		% Col	4.5	6.9	8.4	3.9	3.4	1.4	4.1
		% Total	1.1	0.3	0.0	1.6	0.9	0.0	4.1
	CROP/PASTURE	Acres	1734	326	31	5149	2282	15	9537
		% Row	18.2	3.4	0.3	54.0	23.9	0.2	100.0
		% Col	19.8	19.4	15.3	35.3	24.2	21.7	27.5
		% Total	5.0	0.3	0.1	14.8	6.6	0.0	27.5
	FOREST/RANGE	Acres	2585	419	107	6162	5587	30	14890
		% Row	17.4	2.8	0.7	41.4	37.5	0.2	100.0
		% Col	29.5	24.9	53.0	42.3	59.3	43.5	42.9
		% Total	7.5	1.2	0.3	17.8	16.1	0.1	42.9
	WATER	Acres	9	1	0	20	21	3	54
		% Row	16.7	1.9	0.0	37.0	38.9	5.6	100.0
		% Col	0.1	0.1	0.0	0.1	0.2	4.3	0.2
		% Total	0.0	0.0	0.0	0.1	0.1	0.0	0.2
	COLUMN TOTAL	Acres	8754	1681	202	14570	9422	69	34698
		% Row	25.2	4.8	0.6	42.0	27.2	0.2	100.0
		% Col	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		% Total	25.2	4.8	0.6	42.0	27.2	0.2	100.0

NOTE: See page 10 of text for explantation of table structures.

Table 22

Walnut Creek Battelle LANDSAT Land Use
Error Summary

Battelle LANDSAT vs. Conventional

(refer to TABLE 20)

GRID CELL LEVEL:

Diagonal summation = 44.3%

WATERSHED LEVEL:

	Battelle	Conv.	Diff.
Res.	18.8	17.2	1.6
Com/Ind	6.6	8.9	-2.3
Crop/Pasture/Range	52.3	45.7	6.6
Forest	18.1	25.2	-7.1

Avg. Abs = 4.4%

Battelle LANDSAT vs. UCD LANDSAT
(refer to TABLE 21)

GRID CELL LEVEL:

Diagonal Summation = 40.8%

WATERSHED LEVEL:

	Battelle	UCD	Diff.
Res.	18.8	25.2	-6.4
Com/Ind	6.6	4.8	1.8
Crop/Pasture	27.5	42.0	-14.5
Forest/Range	42.9	27.2	15.7

Avg. Abs = 9.6%

The Battelle LANDSAT and UCD LANDSAT demonstrated similar magnitudes of classification error at the watershed level, both having an average absolute error of 4.4% for the major land use classes. At the grid cell level UCD LANDSAT was more accurate, having "correctly" classified 52.7 to 70.8% of the grid cells compared to Battelle's 44.3%.

COST OF LANDSAT CLASSIFICATION

As part of the overall ASVT project, Water Resources Engineers[1] (WRE) is responsible for a cost-effectiveness study of the LANDSAT determination of land use. HEC kept careful time and cost records during the classification of Crow Creek and Walnut Creek (using the UCD Procedure). The cost data provided to WRE is repeated in Table 23. Five weeks of engineer/technician labor were required for each watershed.

Similarly, cost estimates for the two commercial classifications (Bendix and Battelle) are given in Table 24.

HYDROLOGIC COMPARISON

The primary reason for examining the land use classification ability of LANDSAT was for its potential application to hydrologic modeling. Calibration of hydrologic models typically used by the Corps of Engineers in urban areas is heavily dependent on land use data, particularly in basins where land use is changing and where future conditions are of interest.

The computer program HEC-1 (U.S. Army Corps of Engineers, 1973) has the capability of explicitly relating land use to runoff using two procedures: Snyder's unit hydrograph with percent imperviousness, and the SCS curve number and unit hydrograph (U.S. Soil Conservation Service, 1972). The HYDPAR program (U.S. Army Corps of Engineers, 1978d) obtains the necessary information from a grid cell data bank and computes the specified hydrologic parameters, which are in turn input into an HEC-1 model of the basin. HYDPAR contains a regression equation formulation of Snyder's lag as a function of steam length, length to centroid of subbasin, stream slope, and percent imperviousness, Figure 14. A table associating a percent imperviousness with each land use category in the data bank enables HYDPAR to compute subbasin percent imperviousness from subbasin land use distribution.

---

[1] Water Resources Engineers
8001 Forbes Place,
Springfield, Virginia 22151

Table 23

UCD Procedure
Cost Estimates ($)

Crow Creek

Task	Direct Labor*	Computer and Supplies	Total Direct	Indirect
Preclassification	173	518	691	135
Geometric Registration	173	282	455	135
Clustering	773	161	935	603
Reclustering	459	111	569	358
Postclassification	312	92	404	243
	1,890	1,163	3,053	1,474
		Total	$4,527	

Walnut Creek

Task	Direct Labor*	Computer and Supplies	Total Direct	Indirect
Preclassification	145	366	511	113
Geometric Registration	405	113	518	316
Clustering	616	146	763	481
Reclustering	516	46	562	402
Postclassification	266	71	337	207
	1,947	743	2,690	1,519
		Total	$4,209	

* Base salary rate was $9.26 per hour.

Table 24

Commercial Classification
Cost Estimates

<u>BENDIX (1977)</u>

Contract Administration	$ 600
Contract	$5,607
Travel	$1,800
LANDSAT CCT	$ 400
Aerial Photography	$ 200
TOTAL	$8,607

<u>BATTELLE (1979)</u>

Contract Administration	$1,000
Contract	$2,979
Travel	$2,280
LANDSAT CCT	$ 200
Aerial Photography	$ 160
TOTAL	$6,619

Figure 14

Calculation of Snyder's Lag (TP)

$$TP \text{ (hours)} = (C)\ (X)^{C1}(10)^{(C2)I}$$

Where ---

C = Regression constant = .927600

$X = (L)\ (Z)\ (S)^{-.5}$

L = Stream length (miles)

Z = LCA (Length to centroid in miles)

S = Stream slope (feet/mile)

C1 = Regression coefficient = .387600

C2 = Regression coefficient = -.003735

I = Percent imperviousness

In a similar manner HYDPAR can determine the SCS unit hydrograph parameter from stream length, basin average land slope, and subbasin average cuve number, Figure 15. Curve numbers represent an empirical relationship between hydrologic soil type, land use, and their resultant runoff potential. From a table identifying a curve number with each combination of land use and hydrologic soil type, HYDPAR computes subbasin average curve number.

Figure 15

Calculation of SCS Lag

$$\text{LAG (hours)} = \frac{(L)^{0.8}(S+1)^{0.7}}{(1900)(Y)^{0.5}}$$

Where ---

L = The hydraulic length of watershed in feet

Y = Average subbasin land slope in percent

S = (1000/CN)-10
where CN is the curve number

<u>Rowlett Creek</u>

Percent imperviousness was assigned to Rowlett Creek's LANDSAT and conventional land use categories, Tables 25 and 26, respectively. In addition, two variations on the conventional land use percent imperviousness were made: (1) imperviousness values for the LANDSAT categories were assigned to the aggregated conventional land use categories, Table 27; and (2) the "developing" land use category of Table 26 was changed to 41% imperviousness, everything else remaining the same. The first variation was intended to test the sensitivity of the hydrologic model to aggregation of land use categories by comparing the full 22 category conventional land use results with those generated from a reduced 6 category conventional classification. The second variation was designed to see how hydrologic parameter estimates would change when the "developing" category was equated to "medium density residential".

Table 25

Rowlett Creek LANDSAT Land Use
Percent Imperviousness Summary

LAND USE CATEGORY	TITLE	PERCENT IMPERVIOUSNESS
1	Agricultural	2
2	Natural Vegetation	0
3	Residential	41
4	Commerical/Industrial	85

Table 26

Rowlett Creek Conventional Land Use
Percent Imperviousness Summary

LAND USE CATEGORY	TITLE	PERCENT IMPERVIOUSNESS
1	Low Density Residential	25
2	Medium Density Residential	41
3	High Density Residential	47
4	Multifamily Residential	70
5	Mobile Home Parks	20
6	Central Business District	95
7	Strip Commercial	90
8	Shopping Centers	95
9	Institutional, School, Church, etc.	40
10	Industrial	80
11	Transportation, Major Highways	35
12	Communication, Transformers	35
13	Public Utilities	60
14	Strip Settlement	10
15	Parks and Developed Open Space	6
16	Devloping	15
17	Cropland	3
18	Grassland	0
19	Confined Feeding	20
20	Woodlands, Forest	0
21	Water Bodies	100
22	Barren Land, Gravel Pits	0

Table 27

Rowlett Creek Aggregated Conventional Land Use
Percent Imperviousness Summary

LAND USE CATEGORY	TITLE	PERCENT IMPERVIOUSNESS
1	Agricultural	2
2	Natural Vegetation	0
3	Residential	41
4	Commerical/Industrial	85
5	Developed Open Space	6
6	Water	100

A calibrated HEC-1 model of a 24.6 square miles portion of the Rowlett Creek basin, referred to as Upper Spring Creek and outlined in Figure 16, was used to simulate runoff from selected recurrence interval rainfall. HYDPAR computed percent imperviousness and Snyder's lag for Upper Spring Creek's twenty-three subbasins. Four sets of each parameter are shown in Table 28: (1) conventional 22 category with "developing" = 15% impervious; (2) conventional 22 category with "developing" = 41% impervious; (3) conventional 6 category; and (4) LANDSAT. Percent imperviousness is generally consistent between conventional 22 category and LANDSAT. When substantial differences exist between the two it can usually be explained by the "developing" percent imperviousness or the aggregation effect. Because percent imperviousness is only one of several factors which determine Snyder's lag (see Figure 14), differences between conventional and LANDSAT estimates of subbasin lag are small.

The calibrated HEC-1 model (using the two land use estimates of Snyder's lag) and synthetic rainfall produced the discharge values plotted in Figure 17 for selected stations in the Upper Spring Creek drainage. Differences between such discharge frequency curves can be interpreted as a measure of the hydrologic significance of LANDSAT's misclassification of land use. Considering the uncertainty involved in estimating a frequency curve (even from observed data), the difference between LANDSAT and conventional curves is insignificant.

Pennypack Creek

The SCS curve number method was used to model the Pennypack Creek basin. Curve numbers for conventional 21 categories, LANDSAT 9 categories, and conventional aggregated to 9 categories are given in Tables 29, 30, and 31, respectively. For each of Pennypacks sixty-five subbasins HYDPAR calculated subbasin average curve number and subbasin lag (according to the equation of Figure 15). Also, subbasin average curve number and lag were calculated for (a) <u>all</u> land use categories assigned the <u>industrial</u> category curve numbers,

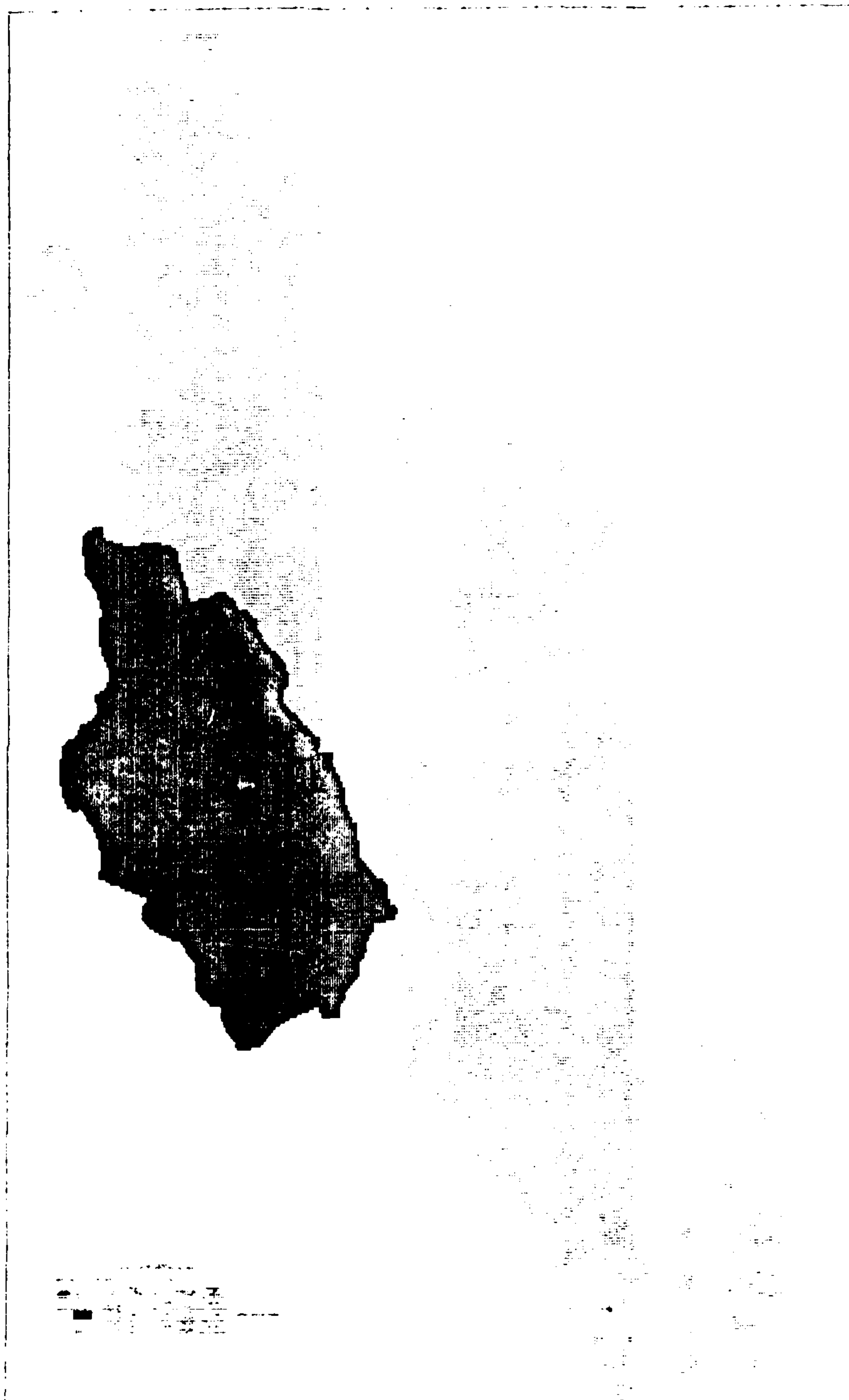

Figure 16
Rowlett Creek
Upper Spring Creek Subbasin

Table 28

Rowlett Creek
Comparison of Hydrologic Model Parameters

SUB-BASIN	% IMPERVIOUSNESS				LAG (HOURS)			
	CONVENTIONAL (22)				CONVENTIONAL(22)			
	DEV=15%	DEV=41%	CONV(6)	LANDSAT	DEV=15%	DEV=41%	CONV(6)	LANDSAT
58	.024	.024	.020	.035	.73	.73	.74	.73
59	.051	.123	.131	.115	.60	.56	.56	.57
60	.035	.066	.066	.071	.49	.48	.48	.48
61	.128	.232	.239	.289	.49	.45	.45	.43
62	.229	.263	.318	.327	.36	.35	.33	.33
63	.100	.125	.145	.132	.39	.38	.37	.38
64	.248	.262	.283	.215	.63	.62	.61	.65
65	.197	.281	.321	.318	.40	.37	.36	.36
66	.173	.207	.246	.215	.52	.50	.49	.50
67	.286	.306	.398	.355	.45	.44	.41	.42
68	.194	.194	.233	.224	.30	.30	.29	.29
69	.240	.244	.288	.192	.49	.49	.47	.51
70	.102	.103	.162	.106	.57	.57	.54	.57
71	.051	.056	.060	.042	.44	.44	.44	.44
72	.268	.318	.369	.251	.31	.29	.28	.31
73	.349	.367	.418	.335	.37	.36	.35	.37
74	.044	.044	.084	.195	.53	.53	.51	.46
75	.072	.072	.120	.081	.31	.31	.30	.31
76	.227	.242	.280	.252	.45	.45	.43	.44
77	.309	.323	.353	.316	.37	.36	.36	.37
78	.256	.275	.333	.309	.41	.40	.38	.39
79	.129	.176	.212	.136	.64	.62	.60	.64
80	.022	.032	.062	.083	.72	.72	.70	.69

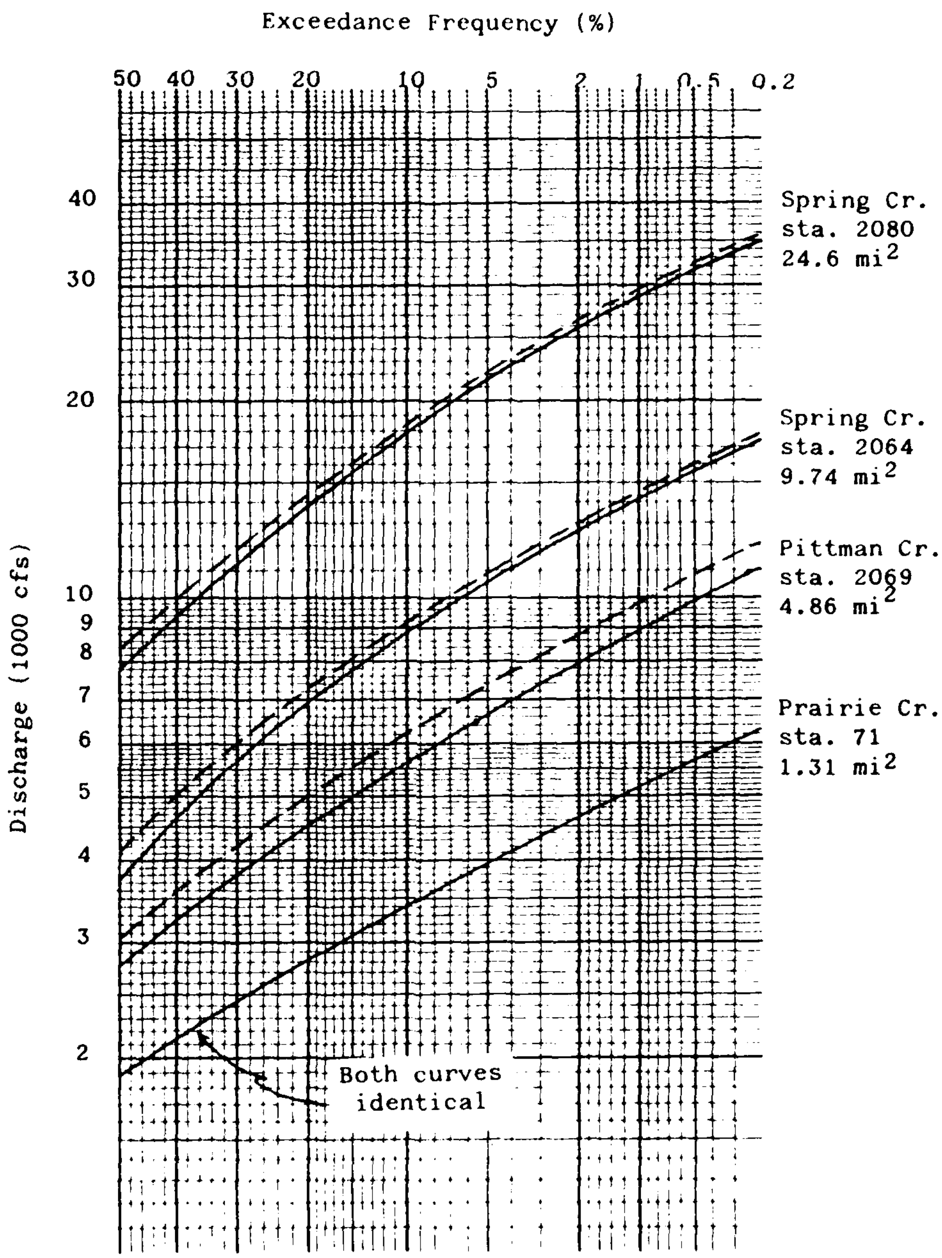

Figure 17
Rowlett Creek
Upper Spring Creek Subbasin

Annual Peak Discharge Frequency
(selected stations)

———————— Conventional Land Use

- - - - - - - - - LANDSAT Land Use

and (b) all land use categories assigned the natural vegetation curve numbers. Parameters estimated in these two cases, and the discharge frequency curves derived from them, demonstrate the possible extremes (in terms of runoff) that could have been generated from the model. Estimates for the five conditions described above are listed in Table 32. Subbasin curve number and lag for conventional, LANDSAT, and aggregated conventional are seen to have nearly identical values.

Table 29

Pennypack Creek
SCS Curve Numbers for Conventional Land Use

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL GROUP A	B	C	D
1	Residential (Single) - High Value	61.	76.	83.	87.
2	Residential (Single) - Low Value	61.	76.	83.	87.
3	Residential (Twins) - High Value	65.	78.	85.	88.
4	Residential (Twins) - Median Value	65.	78.	85.	88.
5	Residential (Twins) - Low Value	65.	78.	85.	88.
6	Residential (Apts) - High Value	81.	88.	91.	93.
7	Residential (Apts) - Low Value	81.	88.	91.	93.
8	Light Industry	81.	88.	91.	93.
9	Heavy Industry	81.	88.	91.	93.
10	Transportation	92.	94.	95.	96.
11	Communication and Utilities	74.	85.	88.	91.
12	Commercial - High Value	89.	92.	94.	95.
13	Commercial - Low Value	89.	92.	94.	95.
14	Community Services - High Value	60.	74.	82.	86.
15	Community Services - Low Value	60.	74.	82.	86.
16	Military	0.	0.	0.	0.
17	Recreation and Cultural	39.	61.	74.	80.
18	Agriculture	62.	75.	83.	84.
19	Mining	79.	82.	84.	85.
20	Forest and Undeveloped Land	40.	63.	75.	81.
21	Water Areas	100.	100.	100.	100.

Table 30

Pennypack Creek
SCS Curve Numbers for LANDSAT Land Use

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL GROUP A	B	C	D
1	Natural Veg	40.	63.	75.	81.
2	Pasture	62.	75.	83.	84.
3	Agricultural	62.	75.	83.	84.
4	Developed Open Space	39.	61.	74.	80.
5	Residential	65.	78.	85.	88.
6	Light Industry	81.	88.	91.	93.
7	Intermediate Industry	81.	88.	91.	93.
8	Heavy Industry	81.	88.	91.	93.
9	Water	100.	100.	100.	100.

Table 31

Pennypack Creek
SCS Curve Numbers for Aggergated Conventional Land Use

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL GROUP A	B	C	D
1	Residential (Single) - High Value	65.	78.	85.	88.
2	Residential (Single) - Low Value	65.	78.	85.	88.
3	Residential (Twins) - High Value	65.	78.	85.	88.
4	Residential (Twins) - Median Value	65.	78.	85.	88.
5	Residential (Twins) - Low Value	65.	78.	85.	88.
6	Residential (Apts) - High Value	65.	78	85.	88.
7	Residential (Apts) - Low Value	65.	78.	85.	88.
8	Light Industry	81.	88.	91.	93.
9	Heavy Industry	92.	94.	95.	96.
10	Transportation	92.	94.	95.	96.
11	Communication and Utilities	81.	88.	91.	93.
12	Commercial - High Value	84.	90.	92.	94.
13	Commercial - Low Value	84.	90.	92.	94.
14	Community Services - High Value	65.	78.	85.	88.
15	Community Services - Low Value	65.	78.	85.	88.
16	Military	0.	0.	0.	0.
17	Recreation and Cultural	39.	61.	74.	80.
18	Agriculture	62.	75.	83.	84.
19	Mining	79.	82.	84.	85.
20	Forest and Undeveloped Land	40.	63.	75.	81.
21	Water Areas	100.	100.	100.	100.

Table 32

Pennypack Creek
Hydrologic Parameter Comparison

SUB-BASIN	CONVENTIONAL 21 CATEGORIES		LANDSAT 9 CATEGORIES		AGGREGATED CONVENTIONAL		ALL INDUSTRIAL		ALL NATURAL VEGETATION	
	CN	LAG	CN	LAG	CN	LAG	CN	LAG	CN	LAG
1	79.3	.65	80.4	.62	80.1	.63	90.4	.44	72.2	.79
2	76.7	.60	79.4	.55	76.9	.59	89.7	.38	69.5	.73
3	79.6	.77	82.9	.69	80.0	.76	90.7	.52	73.7	.91
4	82.7	.72	83.1	.71	82.5	.73	90.7	.54	73.7	.95
5	82.1	.72	84.1	.67	83.2	.69	91.0	.52	74.7	.90
6	79.3	.93	79.2	.93	80.7	.89	89.1	.66	67.4	1.30
7	82.7	.45	83.4	.44	84.4	.42	91.0	.33	75.1	.56
8	84.3	.56	81.2	.63	85.5	.54	89.7	.46	69.9	.87
9	82.9	.76	80.0	.84	81.5	.80	89.3	.60	68.3	1.17
10	83.8	.61	82.1	.65	83.7	.62	90.9	.47	74.5	.82
11	84.2	.44	83.3	.45	83.4	.45	90.9	.34	74.4	.59
12	83.0	.99	83.1	.99	83.8	.96	90.9	.74	74.5	1.29
13	81.6	.77	81.4	.78	81.8	.77	90.3	.56	72.1	1.02
14	83.0	.55	79.7	.61	83.5	.54	89.6	.43	69.5	.82
15	86.5	.50	83.0	.56	86.7	.49	90.7	.42	73.6	.74
16	81.3	.61	81.1	.62	82.0	.60	89.8	.45	69.8	.86
17	78.9	.54	78.7	.55	79.1	.54	89.2	.38	67.6	.75
18	75.9	.45	78.0	.42	76.5	.44	88.4	.30	64.4	.62
19	77.2	.58	77.0	.58	78.6	.56	88.8	.39	66.1	.79
20	77.7	.76	78.9	.73	78.2	.75	90.3	.49	72.1	.89
21	77.2	.80	79.1	.75	78.0	.78	89.2	.53	67.9	1.03
22	77.6	.42	76.9	.42	79.2	.40	88.6	.29	65.2	.59
23	78.4	.63	78.0	.64	79.1	.62	88.7	.44	65.7	.89
24	79.9	.93	79.3	.95	80.7	.91	89.5	.67	68.8	1.28
25	78.9	.57	80.5	.54	80.5	.54	90.0	.38	70.9	.71

Table 32 (Continued)

SUB-BASIN	CONVENTIONAL 21 CATEGORIES		LANDSAT 9 CATEGORIES		AGGREGATED CONVENTIONAL		ALL INDUSTRIAL		ALL NATURAL VEGETATION	
	CN	LAG	CN	LAG	CN	LAG	CN	LAG	CN	LAG
26	80.6	.65	82.1	.62	81.5	0.63	90.7	.45	73.6	.80
27	79.5	.58	79.4	.59	80.6	0.56	89.2	.42	67.7	.82
28	80.7	.54	82.2	.52	81.9	0.52	90.4	.38	72.6	.69
29	75.2	.39	80.0	.37	78.7	0.38	90.1	.26	71.0	.48
30	72.4	.69	73.3	.67	72.8	0.68	89.0	.40	66.8	.80
31	72.6	.61	74.4	.57	73.2	0.60	88.7	.36	65.7	.73
32	71.6	.48	70.6	.49	72.1	0.47	88.6	.28	65.4	.57
33	74.9	.52	75.4	.51	76.2	0.50	88.8	.33	66.0	.66
34	73.2	.83	73.0	.83	74.3	0.80	88.5	.50	64.8	1.03
35	75.0	.62	73.2	.65	75.4	0.61	89.6	.38	68.8	.74
36	75.4	.43	75.8	.42	75.7	0.42	88.9	.27	66.5	.55
37	77.7	.63	80.4	.58	79.0	0.61	89.6	.42	68.9	.81
38	71.4	.52	74.8	.47	72.0	0.51	88.8	.30	66.0	.59
39	73.5	.54	76.6	.49	74.6	0.52	89.0	.32	66.9	.65
40	75.6	.87	75.4	.87	76.6	0.84	88.7	.56	65.6	1.14
41	74.7	.59	77.1	.55	75.7	0.58	89.0	.37	66.8	.73
42	76.1	.55	72.7	.60	77.2	0.53	88.5	.36	64.8	.74
43	75.0	.67	75.2	.67	76.1	0.65	89.4	.42	68.1	.81
44	72.6	.67	75.7	.61	73.7	0.65	88.4	.40	64.6	.83
45	79.0	.49	79.1	.49	79.0	0.49	90.4	.33	71.6	.61
46	72.9	.62	73.9	.60	73.3	0.61	88.9	.37	66.4	.73
47	74.6	.58	72.3	.62	76.2	0.56	88.1	.37	63.5	.78
48	72.9	.73	74.5	.69	74.1	0.70	88.3	.44	64.0	.92
49	71.5	.35	72.9	.33	71.9	0.34	88.2	.20	63.7	.43
50	78.2	.40	78.4	.40	80.1	0.38	88.1	.29	63.2	.60
51	74.7	.70	77.2	.65	76.1	0.67	88.3	.45	64.1	.93
52	77.1	.63	77.1	.63	77.0	0.63	88.8	.42	66.1	.85

Table 32 (Continued)

SUB-BASIN	CONVENTIONAL 21 CATEGORIES		LANDSAT 9 CATEGORIES		AGGREGATED CONVENTIONAL		ALL INDUSTRIAL		ALL NATURAL VEGETATION	
	CN	LAG	CN	LAG	CN	LAG	CN	LAG	CN	LAG
53	72.6	.38	70.0	.41	73.0	0.38	88.4	.23	64.5	.48
54	77.9	.93	77.8	.94	77.6	0.94	88.4	.65	64.7	1.34
55	79.0	.63	78.0	.65	79.1	0.63	88.1	.46	63.5	.97
56	75.9	.90	77.6	.86	77.3	0.87	88.2	.60	63.8	1.25
57	76.0	1.51	75.2	1.54	75.6	1.52	88.4	1.00	64.4	2.06
58	80.4	1.73	79.0	1.81	80.0	1.76	88.7	1.30	65.7	2.63
59	73.3	.67	75.2	.64	73.5	0.67	88.7	.41	65.8	.82
60	80.0	.81	79.5	.83	80.3	0.81	89.2	.59	67.8	1.15
61	79.9	.88	77.3	.95	79.0	0.91	88.0	.67	63.0	1.41
62	80.7	.60	81.4	.59	81.3	0.59	90.0	.43	70.8	.80
63	90.4	.62	83.3	.80	90.4	0.62	90.9	.61	74.6	1.05
64	79.0	.65	79.7	.63	79.1	0.65	89.6	.45	69.3	.85
65	82.1	1.10	79.7	1.19	82.1	1.10	89.3	.85	68.2	1.65

The calibrated HEC-1 model of Pennypack Creek simulated the basin's discharge frequency behavior for conventional, LANDSAT, all industrial, and all natural vegetation conditions. Resulting frequency curves for selected subbasins and the entire drainage area are shown as Figures 18-21. It is clear from these figures, especially with reference to what could have been (i.e., all industrial and all natural vegetation conditions), that differences between LANDSAT and conventionally derived frequency curves are not significant.

Castro Valley

An HEC-1 model of Castro Valley divided the watershed into the four subbasins shown in Figure 22. Similar to the Pennypack Creek analysis, SCS curve numbers were assigned to conventional (Table 33) and LANDSAT (Table 34) land use categories, HYDPAR was used to estimate subbasin average curve number and lag (Table 35), and runoff for selected recurrence intervals was simulated (Table 36) by the calibrated HEC-1 model. As before, discharge frequency values derived from conventional and LANDSAT land use were nearly identical.

Table 33

Castro Valley
SCS Curve Numbers for Conventional Land Use

LAND USE		HYDROLOGIC SOIL GROUP			
CATEGORY	TITLE	A	B	C	D
1	Natural Vegetation	39.	61.	74.	80.
2	Developed Open Space	49.	69.	79.	84.
3	Lo Den Residential	57.	72.	81.	86.
4	Med Den Residential	61.	75.	83.	87.
5	Hi Den Residential	77.	85.	90.	92.
6	Commercial	89.	92.	94.	95.
7	Institutional	69.	80.	86.	89.
8	Water	100.	100.	100.	100.

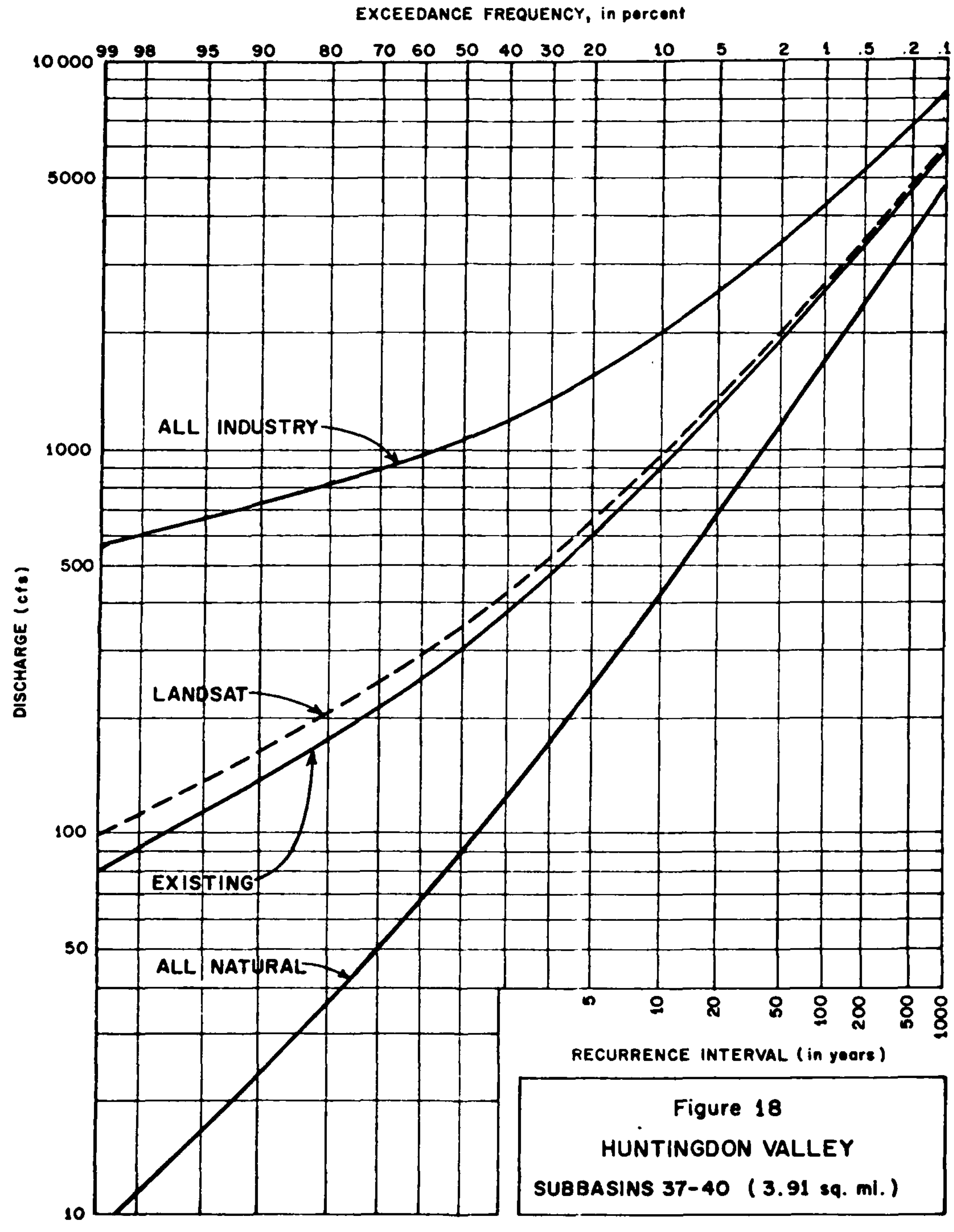

Figure 18

HUNTINGDON VALLEY

SUBBASINS 37-40 (3.91 sq. mi.)

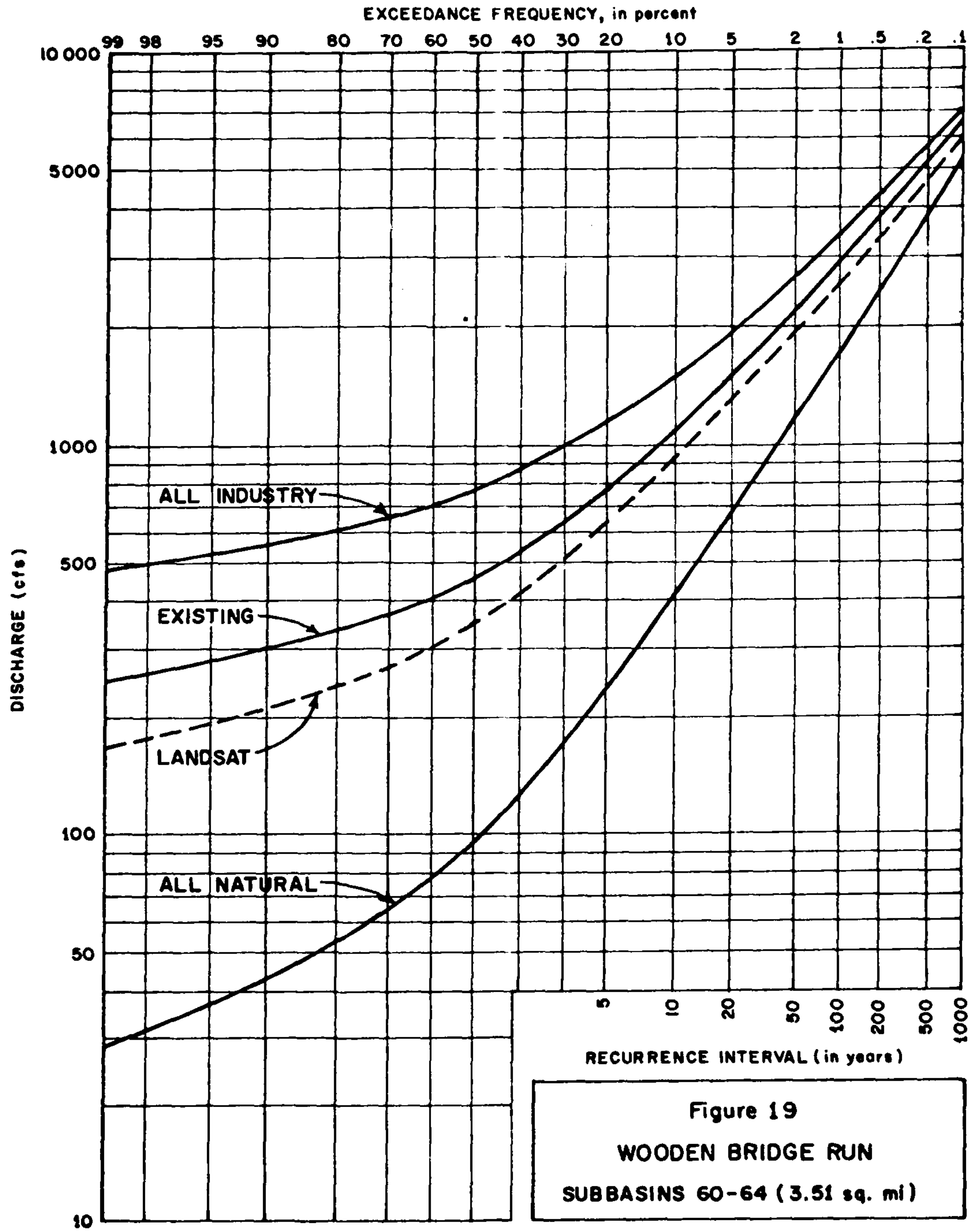

Figure 19
WOODEN BRIDGE RUN
SUBBASINS 60-64 (3.51 sq. mi)

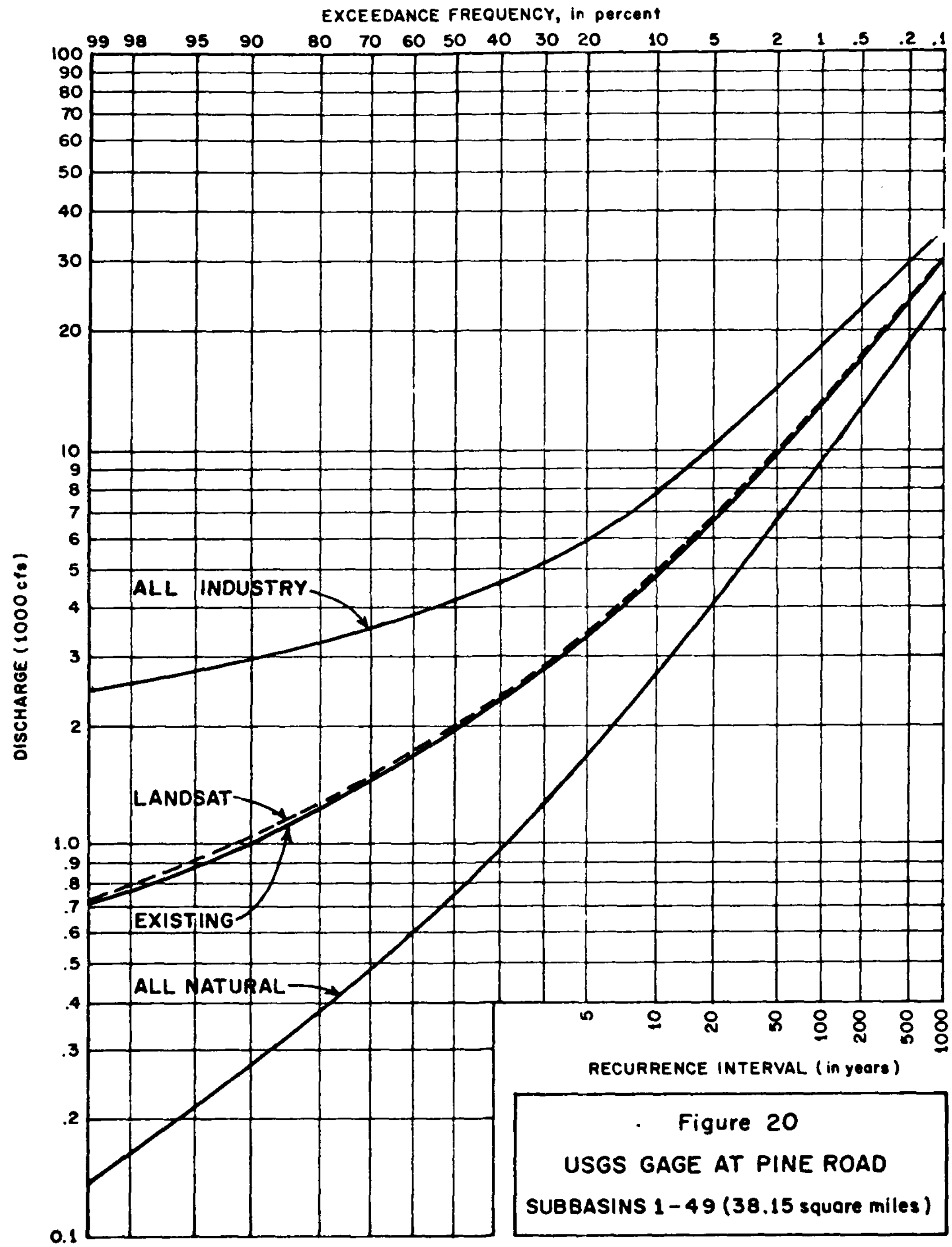

Figure 20

USGS GAGE AT PINE ROAD

SUBBASINS 1-49 (38.15 square miles)

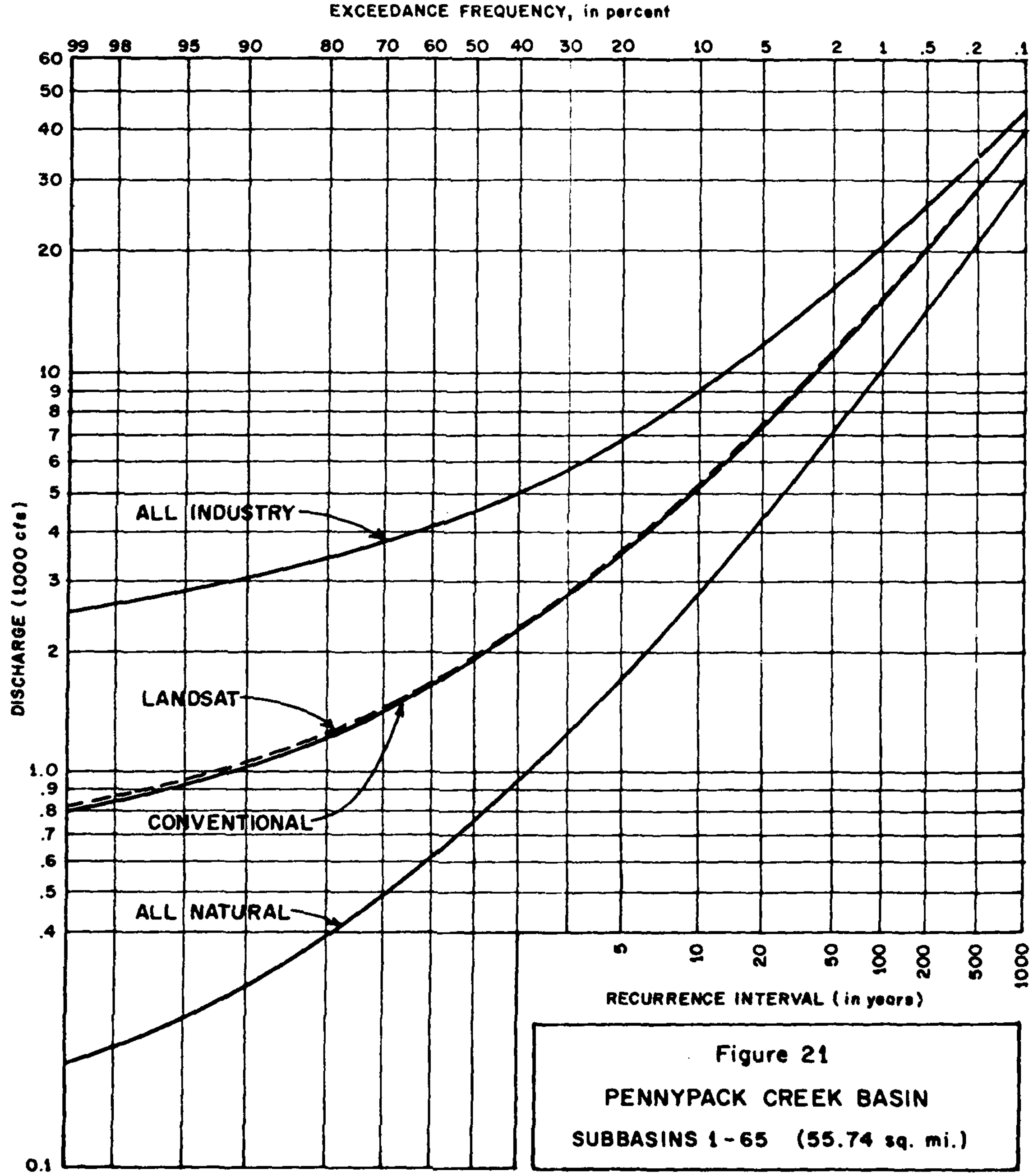

Figure 21

PENNYPACK CREEK BASIN

SUBBASINS 1-65 (55.74 sq. mi.)

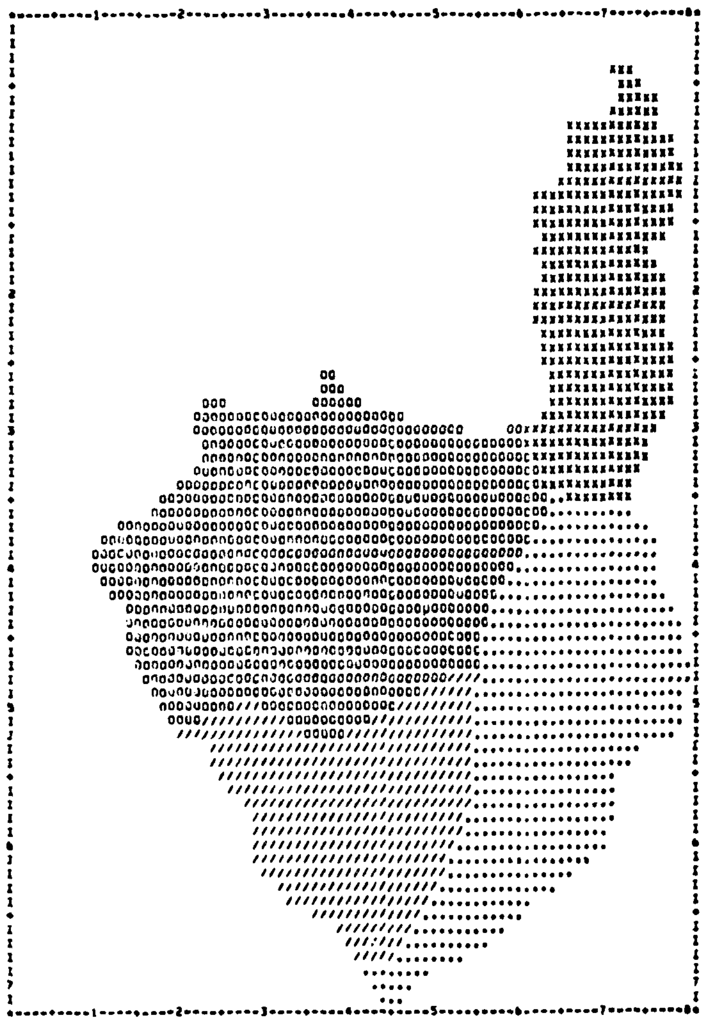

Figure 22

CASTRO VALLEY
SUBBASIN MAP

DATA VALUE EXTREMES ARE 1,000 4,000

LEVEL NUMBER	SYMBOL	VALUE RANGE	PERCENT VALUE RANGE	FREQUENCY	PERCENTILE RANGE	PERCENT OF AREAS	
1	....	1,000 – 1,750	25.00	611	0. – 25.54	25.54	SUBBASIN 1
2	00000000	1,750 – 2,500	25.00	946	25.54 – 65.09	39.55	SUBBASIN 2
3	////////	2,500 – 3,250	25.00	411	65.09 – 82.27	17.18	SUBBASIN 3
4	XXXXXXXX	3,250 – 4,000	25.00	424	82.27 – 100.00	17.73	SUBBASIN 4

Table 34
Castro Valley
SCS Curve Numbers for LANDSAT Land Use

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL GROUP A	B	C	D
1	Natural Vegetation	39.	61.	74.	80.
2	Developed Open Space	49.	69.	79.	84.
3	Residential	61.	75.	83.	87.
4	Commercial/Industrial	85.	90.	93.	94.
5	Water	100.	100.	100.	100.

Table 35
Castro Valley
Comparison of Hydrologic Model Parameters

SUB-	CURVE NUMBER		LAG	
BASIN	CONVENTIONAL	LANDSAT	CONVENTIONAL	LANDSAT
1	85.9	86.3	1.05	1.03
2	84.4	84.6	.51	.51
3	87.9	87.7	.48	.49
4	76.1	76.8	.42	.41

Table 36
Castro Valley
Discharge Frequency Comparison

SUBBASINS	DA (sq. mi.)	RECURRANCE INTERVAL 2-YR	10-YR	25-YR	100-YR	
2	2.20	504	1,019	1,320	1,783	Conv.
		513	1,032	1,334	1,798	LANDSAT
2,3	3.11	595	1,166	1,477	1,948	
		603	1,179	1,490	1,966	
4	1.01	106	295	418	619	
		118	317	446	652	
1,4	2.45	329	700	921	1,270	
		348	730	956	1,311	
1,2,3,4	5.56	905	1,829	2,353	3,169	Conv.
		935	1,876	2,409	3,237	LANDSAT

SUMMARY AND CONCLUSIONS

HEC's participation in the NASA Water Management and Control ASVT has included several tasks, all of which have been completed. An operational procedure for determining land use from LANDSAT imagery has been applied to five watersheds: Crow Creek, Walnut Creek, Rowlett Creek, Pennypack Creek, and Castro Valley (UCD staff performing the work on the latter three watersheds). Detailed grid cell comparisons between conventional and LANDSAT derived land use were made for all except Crow Creek. The alternative land use classifications were also compared hydrologically for all except Crow and Walnut Creeks. Land use for the San Francisco Bay area, including Castro Valley, and Walnut Creek was determined commercially by Bendix Corporation and Battelle Pacific Northwest Labs, respectively. Grid cell comparison of Walnut Creek was repeated for the Battelle classification. Cost and time records for the LANDSAT analysis of Crow and Walnut Creeks were maintained and provided to NASA's cost-effectiveness study contractor.

Based on this work the following conclusions can be made:

(1) At the grid cell level LANDSAT land use was in error approximately 1/3 of the time.

(2) By aggregating land use over the entire watershed, LANDSAT's average misclassification of land use reduces to 2 to 8% for the major land use categories.

(3) The commercial (Battelle) classification was less accurate at the grid cell level than the UCD procedure classification; errors at the watershed level were nearly the same for both.

(4) Evaluated in terms of the difference in discharge frequency curves derived using the same hydrologic model but different land use (LANDSAT and conventional), the LANDSAT derived land use was found to be completely adequate. The number and type of land use categories derived from LANDSAT data were sufficient to be able to apply two standard hydrologic modeling techniques: Snyder's unit hydrograph with percent imperviousness and the SCS curve number method.

(5) The UCD procedure works. It is a complete, self-contained package of computer programs and manual operations that permit a user to identify land use from LANDSAT digital data without requiring the use of expensive interactive image processing equipment.

(6) LANDSAT land use can be directly incorporated into a grid cell data bank, thus providing an automated environment for applying the LANDSAT classification in routine hydrologic investigations.

ACKNOWLEDGEMENTS

HEC's involvement in the ASVT project benefited from the contributions of many individuals. Robert Cermak (HEC) was the principal author of this report. Several other members of the HEC staff were involved in the study: Darryl Davis, Pat Webb, Shelle Barkin, Arlen Feldman, Jerry Willey, Larry Rollins, Bill Eichert, Dale Durnett, and Marilyn Hurst. Corps of Engineers District personnel provided assistance in the application of their grid cell data banks and calibrated hydrologic models: Lynn Lovell, Milburn Smith, Jim Perkins, and Greg Perry (Fort Worth); Frank Shaffer (Philadelphia); and Chuck Farnham (Rock Island). Mr. Lovell also participated in the commercial classification of Walnut Creek. Jay Eliason and Harlan Foote of Battelle Pacific Northwest Labs provided a valuable demonstration of their firms capability in LANDSAT land use classification.

Professors Ralph Algazi and Gary Ford (UCD) developed the UCD Procedure, a working product that will be a valuable contribution to the land use analysis procedures available to the Corps of Engineers. Ms. Doreen Meyer (UCD) was instrumental in documenting the UCD Procedure, training HEC personnel in its application, and providing general problem-solving assistance. Her efforts made a substantial contribution to the success of the project.

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Appendix A

PARTICIPANTS IN THE HEC/UCD/NASA WATER MANAGEMENT AND CONTROL ASVT

Organization	Participants
The Hydrologic Engineering Center (HEC)	Bill Eichert Darryl Davis Arlen Feldman Jerry Willey Pat Webb Robert Cermak
University of California, Davis (UCD)	Prof. Ralph Algazi Prof. Gary Ford Doreen Meyer
National Aeronautics and Space Administration (NASA)	Al Rango Vince Salomonson
Office of the Chief of Engineers (OCE)	Vern Hagen Ming Tseng Walt Duncan
Water Resources Engineers (WRE)	Robert Taylor Tom George

Appendix B

WHAT IS LANDSAT?[1]

LANDSAT is the name of a series of NASA satellites intended to provide earth resources information to the general scientific and environmental planning community. Each Landsat flies in a nearly polar orbit 570 miles (920 km) above the earth's surface, circling the earth every 103 minutes or approximately 14 times per day. The spacecraft views the earth at the same local time, roughly 9:30 a.m. at the equator, on each pass. Repeat coverage from a single satellite occurs every 18 days. LANDSAT-2 and -3 orbits are separated by nine days providing the potential of 9-day repetitive coverage of the earth's surface from space.

The multispectral scanners (MSS), LANDSAT's primary onboard sensor system, measure the earth's reflected sunlight in four spectral bands:

band 4 (green) 0.5-0.6 µm, emphasizes movement of sediment-laden water and delineates areas of shallow water, such as shoals, reefs, etc;

-band 5 (red) 0.6-0.7 µm, emphasizes cultural features, such as metropolitan areas;

-band 6 (near-infrared) 0.7-0.8 µm, emphasizes vegetation, the boundary between land and water, and landforms;

band 7 (near-infrared) 0.8-1.1 µm, provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water, and landforms.

The latest satellite, LANDSAT-3, has an additional band 8 that senses emitted (not reflected) thermal infrared radiation in the range 10.4-12.6 µm. Band 8 measures temperatures between -13°C and 67°C and discriminates relative temperature differences as small as 1.5°C. This band is expected to be useful for monitoring volcanic action, power plant discharges of hot water, and geysers.

The light reflectance data obtained by the MSS sensing system are first converted to electrical signals, which vary in proportion to the intensity measured for each band. These analog signals are then converted into a digital form and transmitted to receiving stations on Earth.

The digital data may be either reformatted into computer compatible tapes (CCTs) or reconverted into sets of black and white photo images. A LANDSAT scene is an imaged ground area normally 185 km (115 mi) crosstrack by 170 km in the spacecraft direction. A LANDSAT scene stored on a CCT contains 2,340 scan lines with 3,240 columns (samples) each, an aggregate of over 7.5 million data elements, called pixels. Each pixel has a numerical reflectance

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[1] Most of this section was extracted directly from the following references: Holkenbrink (1978), LANDSAT Data Users NOTES, Short (1976), Todd (1978) and Watkins (1978).

value in each of the four bands. The nominal area of a pixel is 0.45 ha (57 x 79 m) or 1.11 acres.

LANDSAT photographic imagery is derived from the digital data. Relative reflectance values are assigned gray levels for the production of bands 4, 5, 6 and 7 scene images. Color images are made from combinations of individual black and white images by projecting each given band through a particular filter. In this rendition, called a false color image, growing vegetation will appear in various shades of red, rocks and soils will normally show colors ranging from bluish through yellows and browns, water will stand out as blue to black depending on depth and amount of suspended sediment, and cultural features (towns and roads) will usually be recognized by bluish-black tones arranged in characteristic patterns. Photographic imagery (paper prints) are commonly available in scales ranging from $1:10^6$ to 1:250,000.

Appendix C

CLUSTER ANALYSIS[1]

The aim of any clustering algorithm is to partition a given set of multivariate data points, with little or no knowledge about the actual distribution of the data, into disjoint sets ("clusters") of similar data points. ISOCLAS, the clustering program utilized in the UCD Procedure, attempts to partition the four-dimensional data space[2] into clusters of points having spectral reflectance values that are (1) similar to members of the same cluster, and (2) dissimilar to the points of other clusters. Before describing the actual algorithm, some general terms must be explained.

The center of the I^{th} cluster is represented by the mean, $\mu^{(I)}$, of all points belonging to that cluster.

Distance, d, from a data point $X_k = (x_{k1}, x_{k2}, x_{k3}, x_{k4})$ to the I^{th} cluster is defined as

$$d(X_k, \mu^{(I)}) = \sum_{j=1}^{4} \left| x_{kj} - \mu_j^{(I)} \right|$$

-Standard deviation, $\sigma^{(I)}$, of the I^{th} cluster is equivalent to the standard deviation of all points belonging to the cluster.

-Mean and standard deviation of a cluster are four-dimensional arrays, whereas distance from point to cluster is a single number.

The clustering process starts with all the data assigned to one cluster. The cluster is split into two new clusters along the dimension with the largest standard deviation. Cluster centers are estimated for the two new clusters and distance from each data point to these centers is determined. Points are reassigned to the nearest cluster. Means, standard deviations and point counts of the newly developing clusters are calculated. The splitting process continues until at least 80% of the clusters are not eligible for splitting; i.e., when max $(\sigma^{(I)})$ is less than a specified threshold value of STDMAX.

The program then alternates between combine, split, and delete iterations. Two clusters are combined if the distance between their centers is less than a threshold parameter DLMIN. A cluster is deleted whenever it has fewer than NMIN members. The classification terminates when at least one of the following conditions is satisfied: (1) splitting and combining are no longer permitted because of their respective thresholds; (2) two consecutive iterations are performed with N percent or fewer of the data points involved in a cluster reassignment; or (3) the maximum number of cluster iterations, ISTOP, is reached.

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[1] Parts of this section were extracted from Minter (1977).

[2] One dimension for each of the multispectral scanner's (MSS) four bands.